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ADDENDUM 1 TO
PREDESIGN INVESTIGATIONS QAPP

Northside Sanitary Landfill/
Environmental Conservation
and Chemical Corporation
Indiana

WA 28-5LH2.0
WA 77-5L30.1

January 4, 1988

NONDISCLOSURE STATEMENT

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GLT718/32

Remedial Planning Activities
(REM IV) ZONE II
Contract Number 68-01-7251

ADDENDUM 1 TO
PREDESIGN INVESTIGATIONS
QUALITY ASSURANCE PROJECT PLAN (QAPP)

Project Title: NSL/ECC, Indiana

EPA Nos.: 28-5LH2.0/77-5L30.1

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GLT718/12

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ADDENDUM 1 TO
NORTHSIDE SANITARY LANDFILL (NSL) /
ENVIRONMENTAL CONSERVATION AND CHEMICAL CORPORATION (ECC)
PREDESIGN INVESTIGATIONS QAPP
ZIONSVILLE, INDIANA

PROJECT DESCRIPTION

INTRODUCTION

The United States Environmental Protection Agency (U.S. EPA) requires participation of all U.S. EPA contractors in a centrally managed quality assurance (QA) program. This requirement applies to all environmental monitoring and measurement efforts mandated or supported by U.S. EPA.

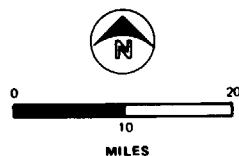
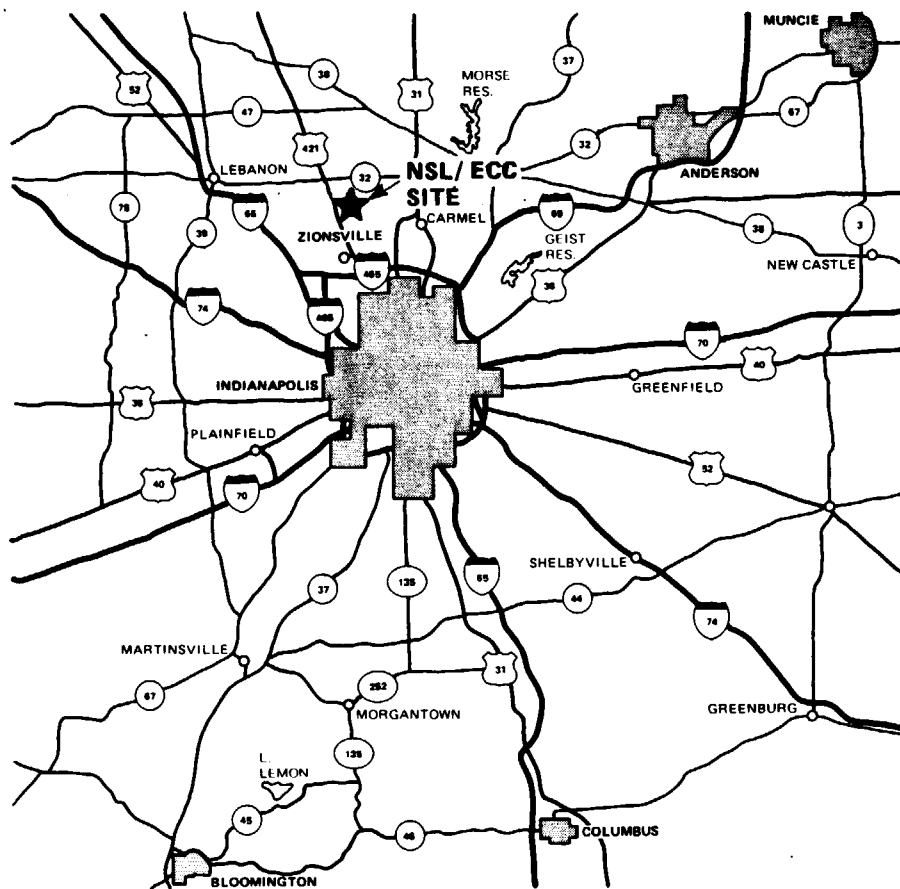
Each contractor generating data has the responsibility to implement minimum procedures to assure that the precision, accuracy, completeness and representativeness of its data are known and documented. To ensure the responsibility is met uniformly, each U.S. EPA contractor must prepare a written Quality Assurance Project Plan (QAPP) covering each project it is contracted to perform.

This document is Addendum 1 to the QAPP submitted to the U.S. EPA (August 1987) for the predesign investigations at the NSL/ECC site near Zionsville, Indiana. This Addendum 1 presents the organization, objectives, functional activities, and specific QA and quality control (QC) activities associated with predesign investigations. Investigations will be conducted at the proposed groundwater interceptor trench area, proposed soil borrow area, existing landfill area, and the area south of the ECC site. To avoid redundancy, this Addendum 1 will refer to the QAPP for the information that has been presented previously.

SITE DESCRIPTION

The ECC and NSL sites are immediately adjacent to each other in a rural area of Boone County, Indiana, south of the intersection of State Route 32 and U.S. Highway 421 and about 10 miles northwest of Indianapolis. The ECC site occupies 6.5 acres immediately west of the 168-acre NSL site. The landfill occupies approximately 70 acres of the NSL site (Figure 1).

The area surrounding the sites is largely undeveloped. Land use to the east and south of the site is agricultural, to the west and north it is residential. Approximately 50 residences are within 1 mile of the site.



LEGEND

- NSL SITE
- ECC SITE
- LANDFILL AREA

SOURCE: U.S.G.S. 7.5 min. quad-range, Roaston, Ind. 1989.

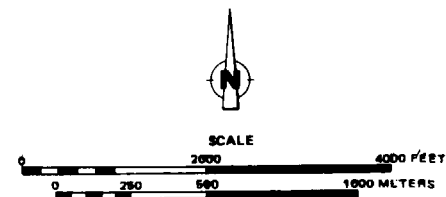
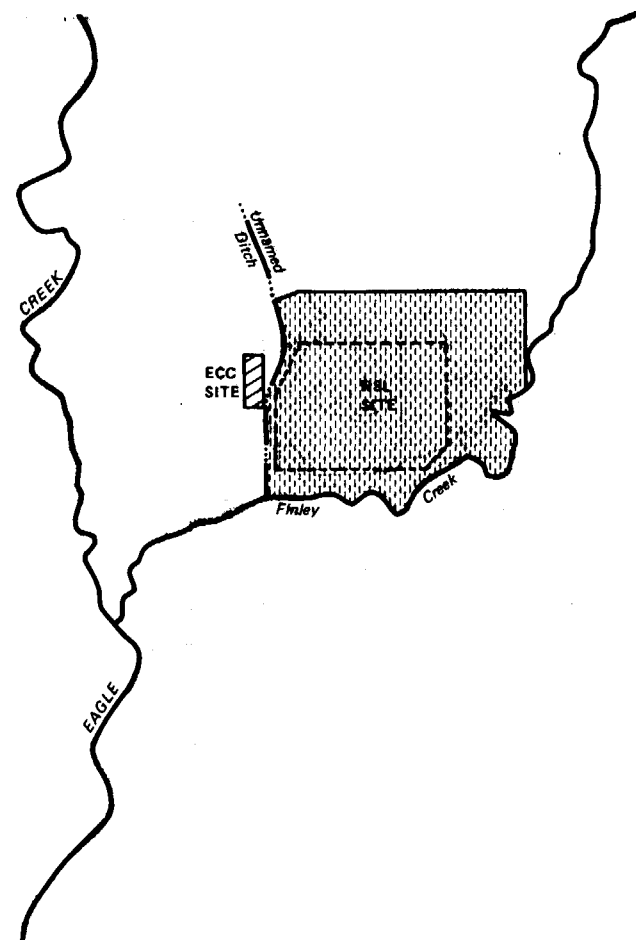


FIGURE 1
LOCATION MAP
NSL/ECC QAPP
ADDENDUM 1

An unnamed drainage ditch that separates NSL from the ECC site flows into Finley Creek near the southwest corner of the landfill. Finley Creek discharges into Eagle Creek about 1/2-mile downstream of the site. Eagle Creek then flows south for about 9 miles before emptying into the Eagle Creek Reservoir, which is used by the City of Indianapolis for a portion of its drinking water supply.

SITE HISTORY OF BACKGROUND

NSL is privately owned and operated as an active solid waste disposal facility. The site has been active since at least 1962 and has accepted various industrial and municipal wastes during the course of its operation. The vice president of NSL has estimated 16 million gallons of hazardous waste have been disposed of in the landfill. A 3-acre oil separation lagoon on the landfill surface is visible in a 1977 aerial photograph. The site has had recurring operational deficiencies as reported by the Indiana State Board of Health (ISBH). The U.S. EPA detected leachate running into Finley Creek, and groundwater contamination was detected in monitoring wells at the site. The site was placed on the National Priorities List in 1983.

ECC began operations in 1977 and was engaged in the recovery/reclamation/brokering of primary solvents, oils, and other wastes received from industrial clients. Waste products were received in drums and bulk tankers and prepared for subsequent reclamation or disposal. Reclamation processes included distillation, evaporation, and fractionation to reclaim solvents and oil.

Several memorandums from ISBH discuss the disposal of ECC wastes in the NSL landfill. ECC wastes reportedly disposed of at NSL include 5,000 gallons/month of waste fluids from the ECC oil reclamation process, still bottoms and solvent recovery waste, 50 to 80 drums/day of paint sludge, thinner, stain and resin sludge, and at least 7,000 drums of unreported contents.

Drum shipments to ECC were halted in February 1982 after U.S. EPA and ISBH investigations found evidence of accumulated contaminated stormwater onsite, inadequate management of drum inventory, and several spill incidents. In 1983 ECC was placed on the National Priorities List (NPL) of hazardous waste sites. U.S. EPA subsequently conducted removal actions at ECC including removal, treatment, and disposal of

cooling pond waters, about 30,000 drums of waste, 220,000 gallons of hazardous waste from tanks, and 5,650 cubic yards of contaminated soil and cooling pond sludge.

Remedial investigations including soil, hydrogeologic, surface water, and sediment investigations of the sites began in 1983 and continued to November 1985. Details of the investigations are included in the ECC and NSL Remedial Investigation Reports. Data for groundwater and leachate samples are attached in Appendix B of the QAPP submitted to the U.S. EPA, August 1987.

Soil contaminants found onsite at the ECC site were primarily volatile organic compounds (VOCs) and phthalates. VOCs in the surface soils have migrated downward. A shallow sand and gravel deposit (approximately 18 feet below ground surface) has also been found to be contaminated with VOCs, though the source may have been derived from a former onsite cooling pond rather than downward migration from the surface soils. Organic contaminants were also found in Finley Creek downstream of the site.

Soil contaminants detected in peripheral subsurface soils at the NSL site were primarily base/neutral organics and some VOCs found at depths of 13 to 15 feet. A sand and gravel

lens at or near the ground surface in the southwest corner of the site was found contaminated with VOCs. PAH and VOC contaminants were also detected in Finley Creek downstream of the site.

The Feasibility Study Reports for the NSL and ECC sites (dated December 5, 1986) contain more detailed information on the nature of site contamination and site hazards. The recommended alternative to remediate the site includes groundwater and leachate collection and treatment.

TARGET COMPOUNDS

The major target compounds of concern at the NSL/ECC site are HSL metals, volatile organic compounds (VOCs), and base/neutral and acid extractable compounds (BNAs) in soil and groundwater. Therefore, sample analyses focus on these compounds. Samples will be analyzed through CLP, RAS, and SAS requiring 30 days of quick turnaround results. Required detection limits for target compounds are listed in Appendix A. In addition, conventional water quality parameters such as COD, TDS, TSS, alkalinity, and chloride will also be measured in the groundwater by the ISBH.

Chemical analyses will be performed only on the groundwater and subsurface soil samples taken in the supplemental

investigation area south of ECC and southwest of NSL site. Field activities at the proposed borrow area and groundwater interceptor trench area adjacent to the south boundary of the landfill will focus primarily on geotechnical and hydrogeological parameters.

PROJECT OBJECTIVES AND USE OF DATA

The objectives of Predesign Investigations for the NSL/ECC site are to collect data needed to implement and design the U.S. EPA selected remedial alternative which includes the following components:

- o Deed and access restrictions of the site
- o RCRA cap over the site
- o Rerouting surface water
- o Leachate collection and treatment
- o Groundwater collection and treatment
- o Monitoring to ensure effectiveness of the remedy components

Refer to the Record of Decision (ROD) of NSL/ECC (September 25, 1987) for the details of the selected remedial alternative.

The Predesign Investigations will be performed in the groundwater interceptor trench area, in the proposed borrow area for landfill cover material, on the existing landfill area, and in the area south of the ECC site and southwest of the landfill as shown in Figure 2. Data collected from the predesign investigations will be used to:

- o Identify and define physical characteristics of the soil and groundwater where the proposed groundwater interceptor alignment will be installed
- o Classify soils in both the proposed borrow area and the existing landfill for landfill cover material
- o Supplement existing information to further define soil and groundwater conditions and contamination in the area south of the ECC site and southwest of the landfill

TASKS OF PREDESIGN INVESTIGATIONS

The tasks and subtasks of Predesign Investigations are:

TAYLOR ROAD

ECC

HWY.

421

DITCH
UNNAMED

NSL

2

FINLEY CR.

LEGEND

- 1 APPROXIMATE AREA FOR SOIL BORING AND TEST PIT EXCAVATION FOR GROUNDWATER INTERCEPTION TRENCH.
- 2 APPROXIMATE AREA FOR SOIL BORING AND TEST PIT EXCAVATION FOR BORROW AREA.
- 3 APPROXIMATE AREA FOR SOIL BORING AND MONITORING WELL INSTALLATION FOR SUPPLEMENTAL INVESTIGATIONS.

▲ APPROXIMATE LOCATION FOR PUMP TEST WELLS

BASEMAP SOURCE: USGS Rosston, Ind. Quadrangle, 1969.

FIGURE 2
AREAS TO BE INVESTIGATED
DURING PRE-DESIGN
NSL/ECC QAPP
ADDENDUM 1



0 500
SCALE IN FEET

o Task FQ--Geotechnical/Hydrological Investigations

- Subtask FQ--Groundwater Interceptor Trench Investigation
- Subtask FQ--Borrow Area Investigation
- Subtask FQ--Miscellaneous Soil Investigation
- Subtask FQ--Geotechnical Laboratory Testing
- Subtask FQ--Pump Testing
- Subtask FQ--Well Installation

o Task F1--Supplemental Field Investigations

- Subtask F1--Supplemental Soil Borings
- Subtask F1--Borehole Soil Sampling
- Subtask F1--Monitoring Well Installation
- Subtask F1--Well Development and Groundwater Level Measurement
- Subtask F1--Groundwater Sampling

The schedule of the tasks is shown in Figure 3. The field activities to be performed during the Predesign Investigations are summarized in Table 1. Description and rationale of each subtask are presented in the following sections.

CIVIL ENGINEERING

Geotechnical Investigations

Pump Test

Supplemental Field Investigations

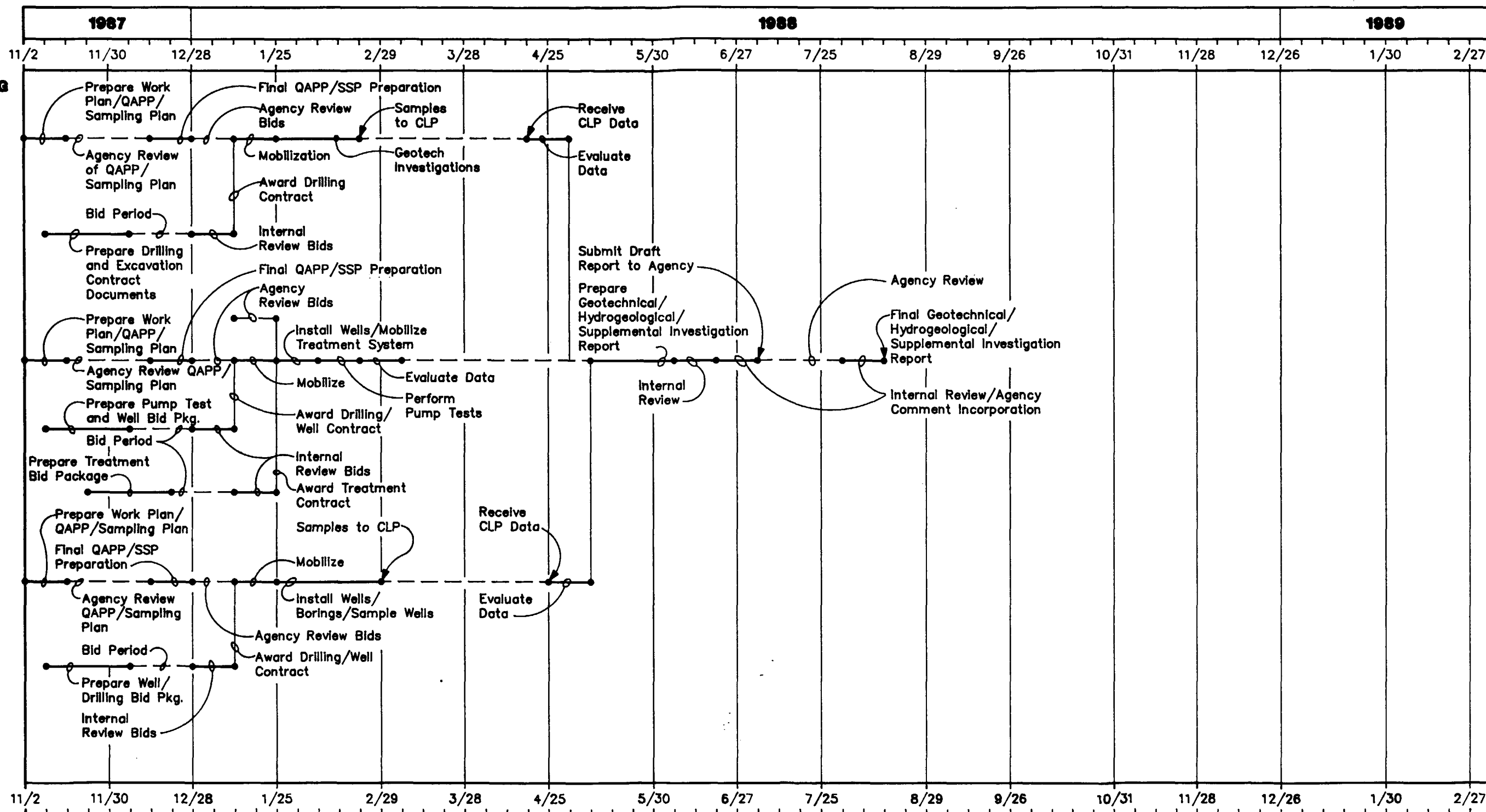


FIGURE 3
SCHEDULE
NSL/ECC QAPP
ADDENDUM 1

Table 1
GEOTECHNICAL/HYDROLOGICAL FIELD INVESTIGATION

SUMMARY

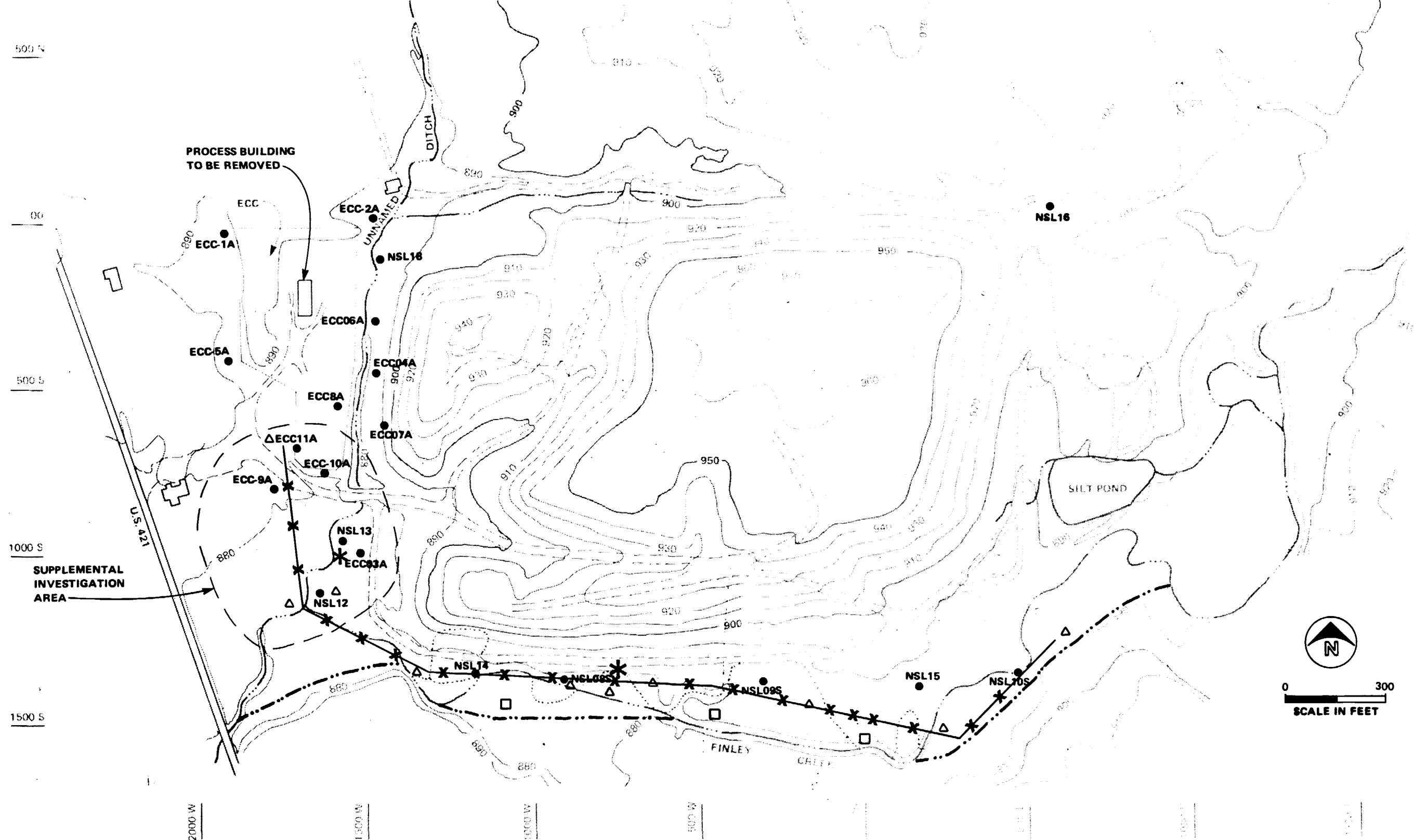
Item	Number				TOTALS	Comments
	Interceptor	Borrow Area	Existing Landfill Cover	Supplemental Investigation Area		
Soil Borings	10 ^a	12 ^a	---	20 ^b	42	^a 2.5-ft. split-spoon intervals ^b 25 to 60 ft. deep 2.0-ft. split-spoon intervals 15 to 30 ft. deep
Cone Penetrometer Soundings	30	20	---	--	50	25 to 60 ft. deep
Test Pits	3	10	---	--	13	10 ft. deep
Observation Wells (2-inch) -Installed, Developed, Sampled, and Surveyed	10 ^a	5 ^b	---	10 ^b	25	^a 25 to 60 ft. deep ^b 15 to 30 ft. deep
Pumping Test Well (4-inch) -Installed, Developed, and Surveyed	2	---	---	--	2	
Pump Tests	2	---	---	--	2	
Field Density Tests	---	---	20	--	20	Sand cone or nuclear gage at/near ground surface
Water Level Measurements	5	20	---	21	46	New (25 wells) and existing (21 wells) wells
In Situ Density	10	---	---	10	20	Determined in the field from tube samples. Water content and specific gravity performed by SAS.

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TASK FQ--GEOTECHNICAL/HYDROGEOLOGICAL INVESTIGATIONS

Subtask FQ--Groundwater Interceptor Trench Investigation

The objectives of the groundwater interceptor trench investigation are to identify and define the soil and groundwater physical characteristics along the proposed trench alignment for design (Figure 4). Approximately 8 to 10 borings and 20 to 30 cone penetrometer soundings will be completed along the proposed trench alignment. The borings will be located at about 500-foot intervals along the alignment and the cone penetrometer soundings will occur at approximately 150-foot intervals. Additional borings or soundings may be performed depending on field observations. Each boring will have a proposed maximum depth of about 60 feet depending on actual subsurface conditions. Soil will be sampled with a standard 2-foot split-barrel sampler at 2-1/2-foot intervals to identify the depth and thickness of sand and gravel lenses along the interceptor alignment. Up to 10 borings will be selected along the alignment for piezometer installations to monitor groundwater levels under static and pumped conditions. The piezometer locations will be selected to provide water level data during the pump tests described under Pump Testing.



- LEGEND**
- GEOTECHNICAL - HYDROGEOLOGICAL
PREDESIGN INVESTIGATION**
- EXISTING MONITORING WELLS
 - △ PROPOSED SOIL BORING LOCATION
 - GROUNDWATER INTERCEPTION SYSTEM
 - X CONE PENETROMETER SOUNDING
 - * PUMP TEST WELL LOCATION
 - TEST PIT LOCATION
 - - - REROUTED FINLEY CREEK

FIGURE 4
GEOTECHNICAL - HYDROGEOLOGICAL
INVESTIGATIONS IN GROUNDWATER
INTERCEPTOR TRENCH AREA
 NSL/ECC QAPP
 ADDENDUM 1

In addition to the soil borings and piezometer installations along the interceptor, three test pits will be completed along the proposed new route of Finley Creek. The test pits along the proposed route of Finley Creek will help to evaluate excavation feasibility for the proposed new creek alignment. All field investigations will be supervised by a professional geotechnical engineer, geologist, or hydrogeologist.

Subtask FQ--Borrow Area Investigation

The objectives of the borrow area investigation are to characterize onsite soil for use as landfill cap and fill material, and to estimate the quantity of borrow material available. Ten to 12 borings will be completed in the proposed borrow area (Figure 5) to depths of about 25 feet. Each boring will be sampled at 2-1/2-foot intervals with standard 2-foot split-spoons. In addition to the borings, 8 to 10 test pit excavations and 15 to 20 cone penetrometer soundings will be completed in the borrow area. Each test pit will be about 8 to 10 feet deep and provide a two-dimensional view of subsurface soil conditions. The cone penetrometer soundings in the borrow area are proposed to supplement the boring and test pit information. Three to five piezometers will be installed to monitor groundwater levels in the proposed borrow area.

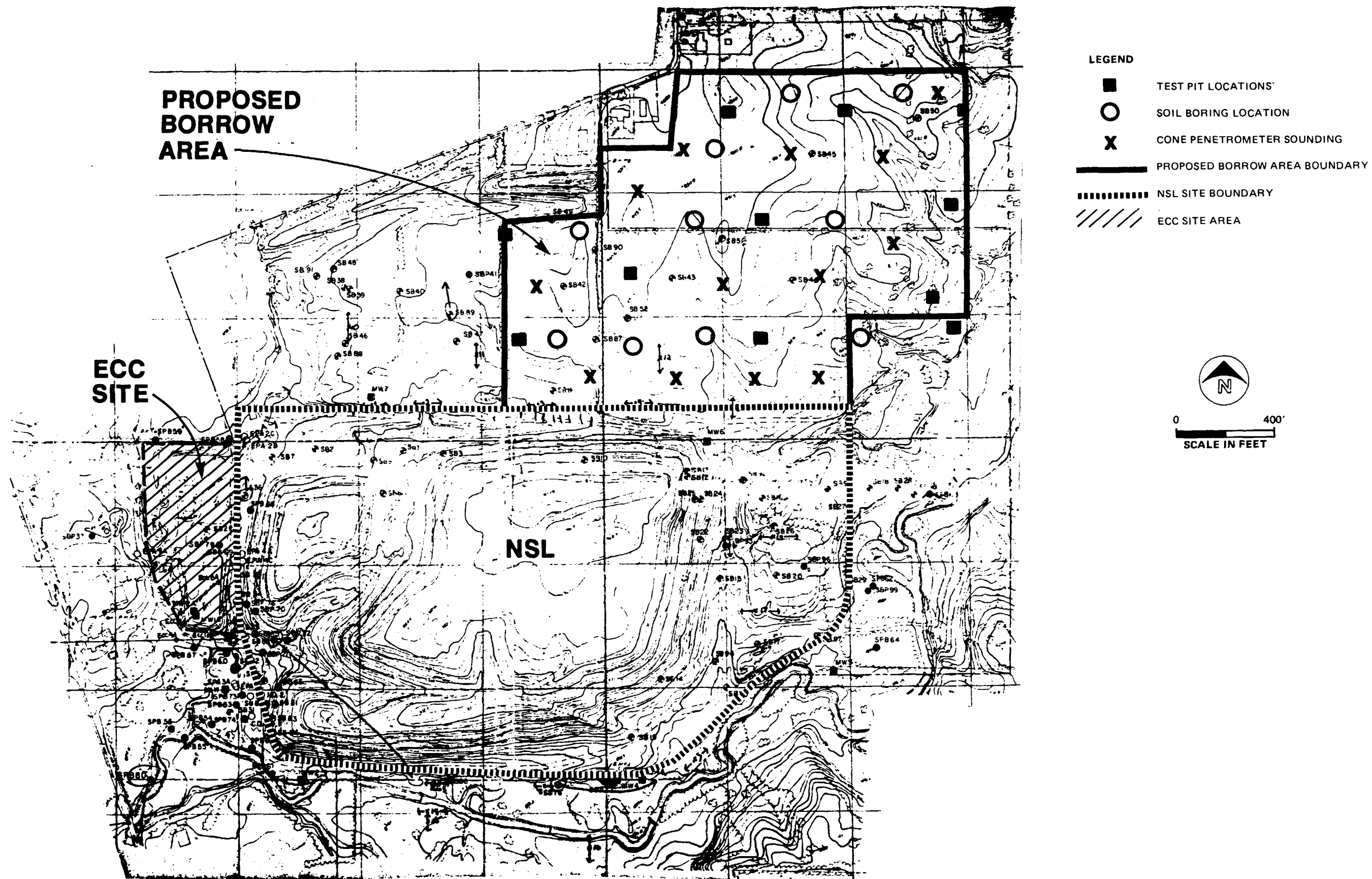


FIGURE 5
SOIL BORING, TEST PIT EXTRACTION,
AND CONE PENETROMETER LOCATIONS
IN THE PROPOSED BORROW AREA
 NSL/ECC QAPP
 ADDENDUM 1

Subtask FQ--Miscellaneous Soil Investigations

In addition to the interceptor and borrow area investigations, the existing landfill cover will be sampled and analyzed for geotechnical soil properties. Bulk soil samples of the existing landfill cover will be collected from the top 6 to 18 inches to evaluate the possible use of the present soil cover as part of the final cap. Also, 15 to 20 field density tests (using sand cones or nuclear density gages) will be performed to evaluate in-place soil densities (see Appendix D).

Subtask FQ--Geotechnical Laboratory Testing

Soil samples will be selected from borings, test pits, and surface locations to determine soil properties and classifications for use in design of the interceptor trench, the rerouted creek channel, the final landfill cap, and to evaluate the existing landfill cover. Soil testings will include:

- o Grain size distribution of soils in the proposed trench alignment, borrow area, and existing landfill (ASTM D 422).

- o Atterberg limits and natural water contents of soil along the proposed trench alignment and of borrow material for the landfill cap (ASTM D 4318).
- o Laboratory compaction tests on soils taken from the proposed borrow area and existing landfill to determine moisture-density relationships for cover evaluation of cap design (ASTM D 1557).
- o Laboratory hydraulic conductivity tests of the remolded, compacted borrow (Permeability Tests with Back Pressure, Chapter VII, "Laboratory Soils Testing," Engineer Manual EM 1110-2-1906, Department of the Army, Office of the Chief of Engineers, Washington, D.C.).
- o Specific gravity tests on soil samples from proposed trench alignment (ASTM D 854).

The laboratory testing will be completed as a special analytical services (SAS) of the U.S. EPA Contract Laboratory Program (CLP) or by a privately contracted geotechnical laboratory. A tentative summary of soil testing is presented in Table 2. Field soil testings, in situ density tests on samples from groundwater interceptor alignment, and field

Table 2
GEOTECHNICAL LABORATORY TESTING SUMMARY

Test/ Designation	Number of Tests Performed				Replicates (3)	TOTALS
	Interceptor	Borrow Area	Existing Landfill Cover	Supplemental Investigation Area		
Particle Size Analysis/ ASTM D-421 and D-422	15	15	5	20	5	60
Atterberg Limits and Water Content/ ASTM D-4318 and D-2216	10	20	---	10	4	44
Moisture-Density Relations/ ASTM D-1557 Method A or C	---	10	5	---	2	17
Hydraulic Conductivity/ (See (1) below)	---	10	---	---	1	11
Specific Gravity/ ASTM D-854	2	---	---	2	2	6
Moisture Content ASTM D-2216 (See (2) below)	10	---	---	10	2	22

- (1) Permeability Tests with Back Pressure, Chapter VII, "Laboratory Soils Testing", Engineer Manual EM 1110-2-1906, Department of the Army, Office of the Chief of Engineers, Washington, D.C.
- (2) Determined from thin-wall tube samples after in situ density measurement at the field (see Table 1). Portions of the tube samples will be sent to the laboratory for moisture content. Test methods may include ASTM D-1587 and D-2937.
- (3) The numbers of replicates are:
1 per 10 for Atterberg limits, hydraulic conductivity, moisture-density relations, and moisture content;
1 per 15 for particle size; 1 per 5 for specific gravity

density tests on the existing landfill cover are listed in Table 1. Samples to be sent for analyses will be selected by the geologist or geotechnical engineer in the field based on geologic conditions encountered and field visual soil classification.

Subtask FQ--Pump Testing

The objectives of aquifer pump tests are to better define the hydraulic properties of the sand and gravel deposits that are to be intercepted by the trench along the south and southwest side of the landfill (Figure 4). The pump tests will provide values of aquifer transmissivity and storativity for estimating construction dewatering requirements, the potential yield of the interceptor, and drawdown along the interceptor.

Two well sites will be identified for pump tests. Each well will be tested individually by pumping and measuring water levels in surrounding piezometers and monitoring wells for a minimum duration of 24 hours to a maximum of 72 hours or until the drawdown in the observation wells remains constant with time.

A test well will be installed south of the NSL site. This test well, which will be finished in a confined glacial sand

and gravel lens within the till, will be pumped at rates of approximately 1 to 5 gallons per minute (GPM) during pump test. Observation wells will be installed as needed within the pumped lens and in other nearby lenses. Existing wells will be used to the fullest extent possible. During the installation of observation wells, if a sand lens is encountered above the lens being tested, at least one piezometer will be finished at this shallow depth. Drawdown measured in the observation well will be used to estimate the degree of hydraulic connection between lenses of sand and gravel zones. The pump test will be conducted continuously for 24 hours at a constant pumping rate.

The second proposed pump test will be conducted in a well finished in the alluvial sand and gravel deposit, north of the confluence of the unnamed ditch and Finley Creek (Figure 4). At this site, the sand and gravel unit is unconfined. The pumping rate in this water table aquifer is expected to range between 5 to 10 gpm. Observation wells will be spread at 10, 20, and 50 feet away from the pumping well. Where possible, existing monitoring wells will be used for observation. Pumping will be conducted continuously for 72 hours at a constant pumping rate.

Prior to each test, a short-duration step-drawdown test will be conducted to establish the constant test pumping rates. Water levels will be measured in the pumping and observation wells during these tests, and will be allowed to stabilize prior to commencing the pumping tests.

Results of the pumping tests will be analyzed with standard equilibrium and nonequilibrium methods to estimate values of transmissivity and storativity.

Subtask FQ--Well Installation

Eight to 10 piezometers and 2 pump testing wells will be installed near the groundwater interceptor alignment shown in Figure 4. Three to five piezometers will also be installed in the borrow area. Additional piezometers will be installed as needed depending on the site conditions and data needs within these areas.

Piezometers and pump testing wells will be constructed of 2-inch and 4-inch PVC, respectively, schedule 40, with number 20 slot screen (0.020 inches). Wells will be screened in sand and gravel lenses. Screen lengths will be determined based on the thickness of sand and gravel lenses encountered

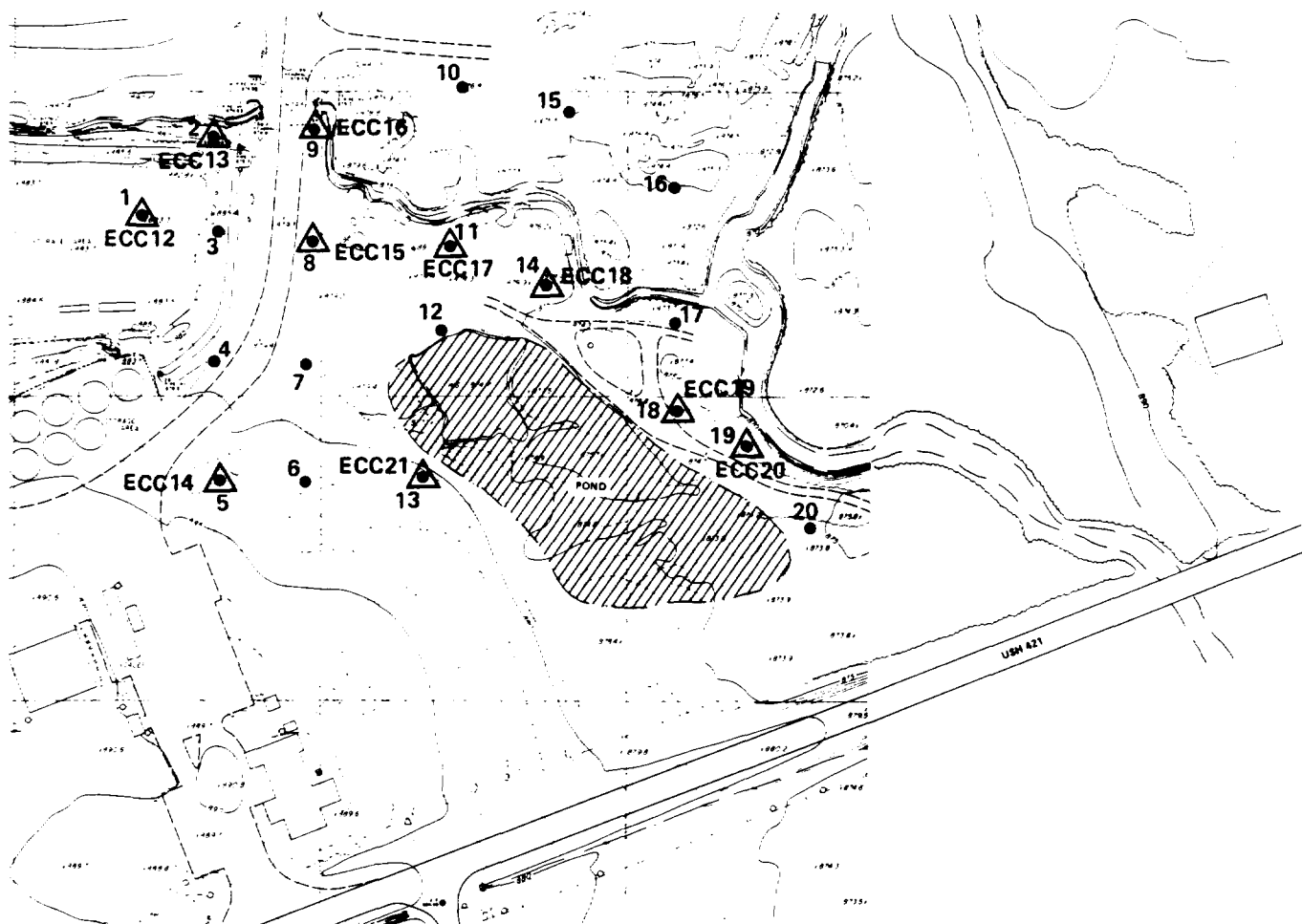
in either the glacial or alluvial sand and gravel layers and will be gravel packed with a clean sand to a level at least 2 feet above the top of the screens. The gravel pack will be sealed with 2 feet of bentonite. The remaining annulus of the boreholes will be filled with a clean bentonite-concrete grout. All wells will be completed in compliance with the requirements of ISBH.

After completing installation of wells, the wells will be developed using the bailing or surge-block method. Each well will be developed until development water is clear of visible sediments. Development water will be collected in 55-gallon drums, or discharged to the creeks at the direction of ISBH.

TASK F1--SUPPLEMENTAL FIELD INVESTIGATIONS

The primary objective of this supplemental investigation is to collect additional information to further characterize the area south of the ECC site and southwest of the landfill shown in Figure 6. Field activities at this area are listed in Table 1.

Results of this supplemental soils and groundwater investigation can be used to define the degree and extent of soil and groundwater contamination immediately south of the ECC site



LEGEND

- 3. SOIL BORING LOCATION
- 2. SOIL BORING & PROPOSED
ECC13 MONITORING WELL LOCATION

NOTE:
ADDITIONAL MONITORING WELLS
COULD BE INSTALLED AT SOIL
BORINGS WITH HIGH HNU OR
OVA READINGS.

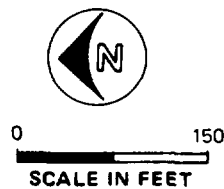


FIGURE 6
PROPOSED BORING LOCATIONS AND
MONITORING WELL LOCATIONS SOUTH
OF THE ECC SITE
NSL/ECC QAPP
ADDENDUM 1

and west of the unnamed ditch and Finley Creek. This task consists of soil borings and sampling, additional monitoring well installation, and groundwater sampling.

Subtask F1--Supplemental Soil Borings

Soil borings and wells will be installed at locations shown in Figure 6, and some of the borings will be done in the area recently investigated by the PRPs. Twenty soil borings will be drilled to depths of 15 to 30 feet below ground surface. In the area of recent alluvial deposits, the borings will be completed to the top of the glacial till. In the areas where alluvium deposits or fill are absent, and glacial till is at or near the ground surface, borings will be advanced through the glacial sand and gravel lenses to the underlying till, which is expected to occur at an elevation of approximately 865 feet above mean sea level.

The soil borings will be advanced using continuous split-spoon sampling. If boring becomes difficult due to wall collapse or flowing sand, hydraulic rotary methods will be used to complete the boreholes to the desired depths.

A boring log for each soil boring will be prepared noting sample intervals, soil classification, and HNu and OVA readings associated with each sample. Where relatively high HNu or OVA readings are noted, soil samples will be taken and monitoring wells will be installed for groundwater sampling.

After collecting soil samples for laboratory chemical and geotechnical analyses, the borings without well installation will be backfilled completely with cement-bentonite grout. Drill cuttings with HNu or OVA readings higher than background levels will be placed and sealed inside 55-gallon drums. Drums will be stored in a secure area onsite until proper offsite disposal is accomplished.

Subtask F1--Borehole Soil Sampling

During advance of the borehole soil samples will be screened for volatile organic contaminants (VOCs) using HNu or OVA readings. Continuous split-spoon samples will be collected from each borehole at 2-foot intervals. Soil samples will be collected for the CLP analyses. These analyses will include chemical analyses, Atterberg limits, moisture contents, specific gravity, and grain size distribution.

Selection of soil samples for chemical analyses will be based on the results of HNu or OVA readings. Samples will be obtained from zones with readings above background. A minimum of one soil sample from each boring will be collected from the water bearing sand and gravel zone. Samples will be analyzed for metals, VOCs, and BNAs through the CLP SAS. The SAS are required for 30-day quick turnaround results.

Thin-wall tube samples will be obtained from 10 selected soil borings. In situ density will be measured for the tube samples at the site. After the measurement, the soil samples will be sent to the CLP for moisture content.

Subtask F1--Monitoring Well Installation

Monitoring wells are proposed for installation at borings where high HNu or OVA readings are recorded. At least 8 to 10 monitoring wells are proposed for installation. The number could increase depending on the site conditions and field observations made at the time of the test drilling.

The objective of the additional monitoring wells is to collect supplemental hydrogeological and groundwater quality data to refine previous interpretations of soil and groundwater contamination at the site.

Monitoring wells will be constructed of 2-inch PVC, schedule 40, with number 20 slot screen (0.020 inches). Procedures of well installation and development are presented in the Task FQ.

Subtask F1--Well Development and Water Level Measurements

After completing installation of monitoring wells, the wells will be developed using bailing or surge-block method. Each well will be developed until development water is clear of visible sediments. Development water will be collected in 55-gallon drums, or discharged to the creeks at the direction of ISBH.

Groundwater levels will be measured in the existing 21 wells (Table 3) and the newly installed monitoring wells. Existing well locations are presented in Figure 4. Water level measurements will be made from the top of the well casing to the static water levels. Water levels will be measured using an electric water level indicator to the nearest 0.1 ft and estimated to the nearest 0.01 ft. A groundwater contour map will be prepared based on the water level measurements.

Table 3
LIST OF EXISTING MONITORING WELLS
FOR WATER LEVEL MEASUREMENT
AT NSL/ECC SITE

<u>Well ID</u>	<u>Well Depth (ft)</u>	<u>Month/Year Installed</u>
ECC-1A ^a	28.5	6/83
ECC-2A	27.5	6/83
ECC-3A ^b	15.0	6/83
ECC-4A	14.0	6/83
ECC-5A	23.7	6/83
ECC-6A	23.0	9/83
ECC-7A	22.0	9/83
ECC-8A	25.0	10/84
ECC-9A	25.0	11/84
ECC-10A ^b	20.0	11/84
ECC-11A ^b	14.0	11/84
NSL-8S	18.0	3/85
NSL-9S	15.0	1/85
NSL-10S	9.0	1/85
NSL-11S	6.5	1/85
NSL-12 ^b	23.0	12/84
NSL-13 ^b	13.5	12/84
NSL-14	9.0	12/84
NSL-15	6.5	1/85
NSL-16	12.0	1/85
NSL-18	13.0	1/85

^aDesignated upgradient wells.

^{a&b}Groundwater samples will be collected.

Subtask F1--Groundwater Sampling

After satisfactory development of wells and water level measurements, groundwater will be sampled. Before sample collection, a minimum of five bore volumes will be purged from each well. Groundwater samples will be collected from the 10 newly installed monitoring wells and from the 6 existing wells listed in Table 3.

Groundwater will be analyzed for HSL metals, VOCs, and BNAs. To detect volatile organics in various concentrations, samples taken from the newly installed wells will be analyzed through the CLP RAS and SAS; SAS will analyze the compounds for low concentrations (lower than CLP contract required detection limits) using low detection limits analyses and for medium concentrations using high hazard protocols (see Appendix B). Samples obtained from the existing wells will also be analyzed by the CLP RAS and SAS; SAS analyzes the volatile organics for low concentrations. Thirty-day quick turnaround for results are required for all chemical analyses.

Groundwater samples will also be analyzed for conventional water quality parameters, COD, TSS, TDS, alkalinity, and

chloride using the ISBH (Appendix B). In addition, pH, specific conductance, and temperature measurements will be conducted in the field (see Appendixes E and F of the August 1987 QAPP).

PROJECT ORGANIZATION AND RESPONSIBILITY

CH2M HILL has overall responsibility for all phases of the Predesign Investigations. CH2M HILL will perform the field investigations and prepare the Predesign Investigations report.

The following responsibilities have been assigned for the project:

- o Remedial Project Manager (RPM)
Karen Vendl (U.S. EPA)
- o Site Manager (SM)
Alpheus Sloan (CH2M HILL)
- o Regional Manager (RM)
Mike Jury (CH2M HILL)

- o Quality Assurance Manager (QAM)
Greg Peterson (CH2M HILL)
- o CH2M HILL Review Team Leader (RTL)
Jim Kennedy (CH2M HILL)
- o Sample Team Leader
Jeff Keiser (CH2M HILL)
- o Geotechnical Field Team Leader
Mark Evans (CH2M HILL)
- o Hydrogeological Field Investigation Team Leader
Elias Zewde (CH2M HILL)
- o Laboratory Operation
Samples for RAS and SAS chemical analysis will be sent to the U.S. EPA Contract Lab Program (CLP). Samples for geotechnical analysis may be sent for SAS to the U.S. EPA Contract Lab Program (CLP) or privately contracted geotechnical laboratories. The SAS conventional water quality parameters of COD, TSS, TDS, alkalinity, and chloride will be sent to Indiana State Board of Health lab (ISBH).

- o System/Performance Audits
CH2M HILL QA Manager (field), U.S. EPA EMSL--Las Vegas (CLP), Contract Project Management Section (CPMS), CRL (ISBH).
- o Special Analytical Services Requests Preparation
CH2M HILL
- o Review of Tentatively Identified Compounds
CH2M HILL
- o QA/QC of CLP Data--U.S. EPA Region V, CPMS (CRL)
- o CLP Data Completeness--CH2M HILL
- o QA/QC of private geotechnical laboratory data--
CH2M HILL
- o QA/QC of Indiana State Board of Health Data--
U.S. EPA Region V, CPMS (CRL)

Primary responsibility for project quality rests with the SM.
A project organization chart is presented in the August 1987
QAPP.

QUALITY ASSURANCE OBJECTIVES

This section is presented in the QAPP.

SAMPLING AND ANALYSES

A summary of all anticipated sampling and analyses at the NSL/ECC site is outlined in Table 4. The compounds to be determined during the Predesign Investigations in the supplemental investigation area are listed in Attachment A-1. A detailed description of sampling methodologies and protocols is presented in the Sampling Plan (Appendix A).

OTHER QAPP ELEMENTS

Refer to the QAPP (submitted to the U.S. EPA, August 1987) for the following QAPP elements:

- o Calibration Procedures and Frequency
- o Analytical Procedures
- o Internal Quality Control Check
- o Data Reduction, Validation, and Reporting

Table 4
PREDESIGN SAMPLING AND ANALYSIS AT MSL/ECC SITE
(page 1 of 2)

TASK	SAMPLE MATRIX	FIELD PARAMETERS	LABORATORY PARAMETERS	NO.	SAMPLES FREQ.	TOTAL	NO.	REPLICATES FREQ.	TOTAL	NO.	SAMPLE BLANKS FREQ.	TOTAL	NO.	MATRIX SPIKE FREQ.	TOTAL	MATRIX TOTAL
FQ-GEOTECHNICAL INVESTIGATIONS --Groundwater Interceptor Area	SOIL	Cone Penetrometer Soundings	Particle Size Analysis SAS (ASTM D-421 & D-422)	15	1	15	1	1	1	0	0	0	0	0	0	16
			Atterberg Limits and Water Content SAS (ASTM D-4318 and D-2216)	10	1	10	1	1	1	0	0	0	0	0	0	11
			Specific Gravity SAS (ASTM D-854)	2	1	2	1	1	1	0	0	0	0	0	0	3
			Water Content SAS (ASTM D-2216)	10	1	10	1	1	1	0	0	0	0	0	0	11
--Borrow Area	SOIL	Cone Penetrometer Soundings	Particle Size Analysis SAS (ASTM D-421 & D-422)	15	1	15	1	1	1	0	0	0	0	0	0	16
			Atterberg Limits and Water Content SAS (ASTM D-4318 and D-2216)	20	1	20	2	1	2	0	0	0	0	0	0	22
			Moisture-Density Relations SAS (ASTM D-1557 Method A or C)	10	1	10	1	1	1	0	0	0	0	0	0	11
			Hydraulic Conductivity SAS (U.S. Dept. of Army EM 1110-2-1906)	10	1	10	1	1	1	0	0	0	0	0	0	11
--Existing Landfill Area	SOIL	Field Density	Particle Size Analysis SAS (ASTM D-421 & D-422)	5	1	5	1	1	1	0	0	0	0	0	0	6
			Moisture-Density Relations SAS (ASTM D-1557 Method A or C)	5	1	5	1	1	1	0	0	0	0	0	0	6
F1-SUPPLEMENTAL INVESTIGATIONS	SOIL	In-situ Soil Density	VOC's consistent with RAS Protocol (1)	20	1	20	2	1	2	1	1	1	2	1	2	23
			A,B/N Extractables RAS Protocol (1)	20	1	20	2	1	2	1	1	1	2	1	2	23
			Metals consistent with RAS Protocol (1)	20	1	20	2	1	2	1	1	1	2	1	2	23
			Particle Size Analysis SAS (ASTM D422)	20	1	20	2	1	2	0	0	0	0	0	0	22
			Atterberg Limits and Water Content SAS (ASTM D4318)	10	1	10	1	1	1	0	0	0	0	0	0	11
			Specific Gravity SAS (ASTM D-854)	2	1	2	1	1	1	0	0	0	0	0	0	3
			Water Content SAS (ASTM D-854)	10	1	10	1	1	1	0	0	0	0	0	0	11

Table 4
 PREDESIGN SAMPLING AND ANALYSIS AT NORTHSIDE/ENVIRO-CHEM SITE
 (page 2 of 2)

TASK	SAMPLE MATRIX	FIELD PARAMETERS	LABORATORY PARAMETERS	NO.	SAMPLES FREQ.	TOTAL	NO.	REPLICATES FREQ.	TOTAL	NO.	SAMPLE BLANKS FREQ.	TOTAL	NO.	MATRIX SPIKE (2) FREQ.	TOTAL	MATRIX TOTAL
F1-SUPPLEMENTAL INVESTIGATIONS (continue)	GROUNDWATER	pH	VOC's consistent with RAS Protocol (1) Unfiltered Samples SAS Quick Turnaround	16	1	16	2	1	2	2	1	2	2	1	2	20
		Specific Conductance														
		Temperature	A,B/N Extractables (1) consistent with RAS Protocol SAS Quick Turnaround	16	1	16	2	1	2	2	1	2	2	1	2	20
			Metals consistent with RAS Protocol (1) Filtered Samples SAS Quick Turnaround	16	1	16	2	1	2	2	1	2	2	1	2	20
			Chemical Oxygen Demand See ISBH protocol in the QAPP Unfiltered Samples	16	1	16	2	1	2	2	1	2	2	1	2	20
			Residue, filterable See ISBH protocol in the QAPP Unfiltered Samples	16	1	16	2	1	2	2	1	2	2	1	2	20
			Total Dissolved Solids See ISBH protocol in the QAPP Unfiltered Samples	16	1	16	2	1	2	2	1	2	2	1	2	20
			Alkalinity See ISBH protocol in the QAPP Unfiltered Samples	16	1	16	2	1	2	2	1	2	2	1	2	20
			Chloride See ISBH protocol in the QAPP Unfiltered Samples	16	1	16	2	1	2	2	1	2	2	1	2	20
			VOC's consistent with SAS High Hazard Protocol (3) Unfiltered Samples	10	1	10	1	1	1	1	1	1	2	1	2	12
			VOC's consistent with RAS Protocol (1) Unfiltered Samples SAS Low Detection Limit	16	1	16	2	1	2	2	1	2	2	1	2	20

Notes:

1. See Attachment A-1 of Appendix A for a complete list of parameters.
2. Matrix spikes (MS) and matrix spike duplicates are not included in the total number of samples. These numbers represent samples for which extra volume must be collected for the laboratory to perform contract required QC analyses.
 For groundwater spike and matrix spike duplicates, double the sample volume for volatiles; triple volume is required for acid, base/neutral extractables.
3. Groundwater samples may contain medium levels of volatile organic compounds to be analyzed using U.S. EPA high hazard protocol.

- o Performance and System Audits
- o Preventive Maintenance
- o Specific Routine Procedures used to Assess Data Precision, Accuracy, and Completeness
- o Corrective Action
- o Quality Assurance Reports to Management

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Appendix A
SAMPLING PLAN

PREDESIGN INVESTIGATIONS
NORTHSIDE SANITARY LANDFILL/
ENVIRONMENTAL CONSERVATION AND CHEMICAL CORPORATION
INDIANA

Appendix A
SAMPLING PLAN

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Attachment A-1. Hazardous Substance List (HSL) and
Contract Required Detection Limits
(CRDL)

Table

A-1 Sample Types, Bottles, and Preservatives

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Appendix A

SAMPLING PLAN

NORTHSIDE SANITARY LANDFILL (NSL) /

ENVIRONMENTAL CONSERVATION AND CHEMICAL CORPORATION (ECC)

PREDESIGN INVESTIGATIONS

INDIANA

OBJECTIVE

This sampling plan documents procedures and practices to be followed during Predesign Investigations at the NSL/ECC site. This plan will be used in obtaining soil and groundwater samples. It will also be used in the performance of soil borings, monitoring well installations, and excavation of test pits.

SAMPLE LOCATIONS, NUMBERS, AND ANALYSES

Sampling will occur at the proposed groundwater interceptor trench area, soil borrow area, existing landfill area, and supplemental investigation area south of the ECC site and southwest of the landfill. Borehole soil sampling locations are shown in Figures 4, 5, and 6 of Addendum 1. Soil sample

numbers and analytical parameters are summarized in Tables 1, 2, and 4 of Addendum 1. Groundwater samples will be collected from the existing wells and from the newly installed wells in the supplemental investigation area. Proposed groundwater sampling locations are shown in Figures 4 and 6 and sample numbers and analyses are listed in Table 4 of Addendum 1.

SAMPLE DESIGNATION

A CH2M HILL sample numbering system will be used to identify each sample for analysis, including duplicates and blanks. A Sample Management Office (SMO) number and a Central Region Lab (CRL) number will also be assigned to each sample at the same time. Refer to the User's Guide of the CLP for an explanation of the SMO numbers. Refer to the CRL Sample Handling Manual for an explanation of the CRL number. A listing of sample identification numbers will be maintained in the sampling log book by the team leader. Each CH2M HILL sample number will consist of three components as described below:

PROJECT IDENTIFICATION

A three-letter designation will be used to identify the portion of the site where the sample is collected. For this

project, the designation will be NSL for NSL and ECC for ECC.

SAMPLE TYPE AND LOCATION CODE

Each sample will have a two-digit alpha code corresponding to the sample type, followed by the sample location number. The alpha-codes are as follows:

- o SB--subsurface split-spoon soil samples
- o GW--monitoring well sample
- o FB--field blank

Samples of predesign investigations will have an alphanumeric sample location code after the code of sample type. Field blanks will have an FB following the alpha code for the type of sample (i.e., a groundwater blank will be GWFB). Replicate samples will be identified by "99".

SAMPLE EVENT AND SEQUENCE CODE

Soil samples will be given a sequential code indicator that will indicate the depth at which the sample was taken. For example, if soil borings are sampled at 2-foot intervals, a sequential code indicator of "04" would mean the fourth sample in the sequence.

EXAMPLES OF SAMPLE NUMBERS

Examples of sample numbers are as follows:

- o NSL-SB08-02--NSL site, second sample collected from soil boring 08, depth to be noted in logbook
- o ECC-GWECC20-02--ECC site, second groundwater sample collected from monitoring well ECC20
- o ECC-GWECC13-99--ECC site, replicate sample collected from well ECC13

GENERAL SAMPLING AND TESTING PROCEDURES

SOIL BORING AND SAMPLING

Soil borings will be advanced to collect subsurface soil samples using hollow-stem augers. Continuous split-spoon samples will be collected starting at the surface with 2- to 2-1/2-foot intervals. Selected subsurface samples will be sent to the lab for analysis and monitoring wells will be installed at selected soil boring locations. The remainder of the borings will be abandoned by cement/bentonite grouting, to seal off any potential path of vertical migration of contaminants.

Standard Penetration Tests (SPT) will be performed concurrently with soil sampling to obtain a measure of the resistance of the soil to penetration of the sampler. The number of blows is required to effect each 6 inches of penetration of a split-spoon sampler (split-barrel sampler) or fractions thereof. The first 6 inches is considered to be a seating drive. The number of blows required for the second and third 6 inches of penetration added is termed the penetration resistance. The procedures of soil boring and sampling are described in ASTM D 1452 and ASTM D 1586 (Appendix C).

Split-spoon samples will be visually described for soil composition, structure, consistency, color, and conditions, and the soil will be classified according to the Unified Soil Classification System (USCS). Soil samples from borings will be tested for geotechnical parameters, laboratory compaction, Atterberg limits, particle size distribution, hydraulic conductivity, moisture content, and specific gravity. During advancing of the split-spoon, the holes will be descriptively logged and checked with an HNu or OVA.

TEST PIT

Approximately 13 test pits will be excavated in the proposed soil borrow area and along the proposed new route of Finley

Creek. The maximum depths of excavation is expected to be 10 feet. Each test pit will be logged and photographed to document the subsurface conditions encountered.

Following completion of sampling and test pit logging, each test pit will be backfilled to grade. Disposal of any remaining material will be determined from HNu or OVA screening results. If the soils show evidence of organic contamination with HNu readings above background, they will be drummed and removed to the secure storage area.

WELL INSTALLATION AND GROUNDWATER SAMPLING

Two pump testing wells and 15 piezometers will be installed in the proposed groundwater interceptor trench area and soil borrow area. In addition, 10 groundwater monitoring wells will be installed in selected soil boring locations of the supplemental investigation area.

Groundwater sampling will be conducted for 10 newly installed monitoring wells in the supplemental investigation area and for 6 existing wells as shown in Table 3 of Addendum 1. Details of well installation and groundwater sampling are presented in Addendum 1 (section: Project Objectives and

Use of Data) and in the sampling plan of the August 1987 QAPP.

FIELD SOIL INVESTIGATIONS

Cone penetrometer soundings will be conducted in the proposed groundwater interceptor trench area and in the soil borrow area. Two soil density tests, field density tests and in situ density tests, will also be performed in the field as follows: field density tests in the landfill area; in situ density tests in the groundwater interceptor trench area and in the supplemental investigation area. For in situ density tests, a thin-wall tube sample will be taken. After in situ density field measurements, samples will be sent to the CLP for moisture content. The procedures of field soil testings are presented in the ASTM as follows:

- o Cone penetrometer sounding--ASTM D 3441
- o Field density test--ASTM D 1556 or D 2922
- o In situ density test--ASTM D 1587 and D 2937

The ASTM methods are attached in the Appendix D.

REPLICATE SAMPLE, BLANK SAMPLE, AND MATRIX SPIKE SAMPLE PREPARATION

Replicate, blank, and matrix spike samples of groundwater and soil will be collected in the field and submitted to the CLP to assess the quality of the data from sampling efforts. Replicate samples will be used to assess the combined effects of sample collection, handling and analysis on data precision. Field blanks will be collected and analyzed to determine the extent to which field procedures contribute to sample contamination.

Replicate samples must be collected at the same time, at exactly the same location, with the same apparatus, and into identical containers prepared in the same way, and filled to the same volume. All replicate samples are preserved and handled identically. Blank samples are deionized, contaminant-free water or clean sand that is collected, containerized, treated, and handled in the same manner as the samples. Matrix spike samples are additional samples to be spiked with certain chemicals in CLP lab for Quality Assurance/Quality Control (QA/QC) of analytical process.

The number of sample replicates, blanks, and matrix spikes are listed in Table 4 of Addendum 1. The number of matrix spike samples is not included in the total number of samples. For groundwater, one replicate sample and one blank sample will be collected per day or for each 10 samples, whichever

is more frequent. For soil, one replicate sample will be collected per day or for each 10 samples, whichever is more frequent, and one blank sample will be collected for each 20 samples.

Soil Matrix Blanks

Soil sample blanks will consist of a clean, washed, uniform sand such as an Ottawa sand. The blank will be prepared by collecting the blank material with the same decontaminated scoop used to collect soils and by following soil sampling and handling protocols.

The blanks for soil boring samples will be prepared by collecting the blank material in a decontaminated brass sleeve and transferring it to the appropriate sampling container using decontaminated stainless steel spatulas or spoons.

Water Matrix Blanks

Groundwater matrix blanks will be prepared using reagent grade deionized water. Groundwater well sample blanks will be prepared by pouring the deionized water into the bailer and transferring it to appropriate sample containers. The metals sample

blank will be filtered. All blanks will be preserved and handled as if they were actual samples.

EQUIPMENT DECONTAMINATION PROCEDURES

All heavy equipment used during drilling (i.e., drilling rig, augers, drilling tools, etc.) will be decontaminated between each exploratory location using a high pressure hot water or steam washer away from any sampling area on a designated decontamination pad. Decontamination fluids may be collected or discharged depending on HNu or OVA readings. Soils and mud from the decontamination may be drummed for eventual disposal if HNu or OVA readings are above background.

All sampling and well purging equipment (trowels, trays, beakers, pumps, filter apparatus, bailers, split-spoon sleeves, etc.) will be decontaminated between each successive sample collection point. Decontamination will consist of removal of dirt or mud by scrubbing in a tap water wash. The equipment will then be washed in a solution containing 2.5 percent (w/w) trisodium phosphate solution followed by a 10 percent (v/v) methanol deionized water solution and finally a triple deionized water rinse. When pumps are used the decontamination solutions will be pumped through the pump and hoses. Sampling equipment will be placed on a clean plastic sheeting

and will be allowed to air dry as much as possible before being used again.

SAMPLE HANDLING AND ANALYSES

PARAMETERS

The parameters of sample analysis are listed in Table 4 of Addendum 1. Samples for chemical analysis may be low or medium concentration samples based on CLP criteria. The determination will be made in the field. The SMO will be notified as soon as this determination is made so that the designated CLP lab can be notified.

Measurement of pH, specific conductance, and temperature will be performed in the field on all groundwater samples. The procedures of field measurement are presented in Appendix E and F of the August 1987 QAPP.

SAMPLE PREPARATION

Preparation procedures for samples are summarized in Table A-1. All preservatives added will be prepared using reagent grade chemicals. Specific chemical preservatives are described in

Table A-1
SAMPLE TYPES, BOTTLES, AND PRESERVATIVES
NSL/ECC PREDESIGN INVESTIGATIONS
(Page 1 of 2)

Sample Type	Analysis	Bottles	Preservation	Holding Time	Quantity	Method of Shipment	Packing
Groundwater Low	RAS Organics						
	- Acid extractables, base/neutral extractables	One 1/2-gallon amber bottles (Teflon lined-caps)	Iced to 4 C	5 days for extraction 40 days for analysis	Fill to Shoulder	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	- Volatiles	Two 40-ml volatile organic analysis vials	Iced to 4 C	7 days	Fill to top, no air space	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	RAS Inorganics						
	- Metals	One 1-liter polyethylene bottle	HNO ₃ to pH <2, Iced to 4 C	6 months	Fill to Shoulder	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	- Mercury	One 1-liter polyethylene bottle	HNO ₃ TO pH <2, Iced to 4 C	28 days	Fill to Shoulder	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	SAS						
	- COD	One 1-liter polyethylene bottle	Iced to 4 C H ₂ SO ₄ TO pH <2,	28 days	Fill to Shoulder	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	- Total suspended solids Total dissolved solids Alkalinity Chlorides	One 1-liter polyethylene bottle	Iced to 4 C	7 days 48 hours 14 days 28 days	Fill to Shoulder	Daily by overnight carrier	Vermiculite or Poly-foam cooler
Groundwater Medium	RAS Organics						
	- Volatiles	Two 40-ml volatile organic analysis vials	Iced to 4 C	Not established	Fill to top, no air space	Federal Express Priority 1 with restricted article paperwork	in cans with vermiculite

Note: Groundwater samples for matrix spikes and matrix spike duplicates will require twice the volume and double the number of bottles for volatile organic analysis.
For acid, base/neutral extractables and pesticides/PCB's, triple the volume is required.

Table A-1
SAMPLE TYPES, BOTTLES, AND PRESERVATIVES
NSL/BCC PREDESIGN INVESTIGATIONS
(Page 2 of 2)

Sample Type	Analysis	Bottles	Preservation	Holding Time	Quantity	Method of Shipment	Packing
Soil Low	RAS Organics						
	- Acid extractables, base/neutral extractables	One 8-oz wide mouth glass jar	Iced to 4 C	Extract within 10 days Analyze within 10 days	Fill 3/4 full	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	- Volatiles	Two 120-ml wide mouth glass vials	Iced to 4 C	Extract within 10 days Analyze within 10 days	Fill 3/4 full	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	RAS Inorganics						
	- Metals	One 8-oz wide mouth glass jar	Iced to 4 C	6 months	Fill 3/4 full	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	- Mercury	One 8-oz wide mouth glass jar	Iced to 4 C	28 days	Fill 3/4 full	Daily by overnight carrier	Vermiculite or Poly-foam cooler
	S&S						
	- Grain size distribution	Two 8-oz wide mouth glass jars	none	none	Fill 3/4 full	Daily by overnight carrier	in cans with vermiculite
	- Atterberg Limits & Water Content	Two 8-oz wide mouth glass jars	none	30 days	Fill 3/4 full	Daily by overnight carrier	in cans with vermiculite
	- Hydraulic Conductivity	One 5-gallon plastic container	none	none	Fill 3/4 full	Daily by overnight carrier	5-gallon bucket
	- Laboratory Compaction	One 5-gallon plastic container	none	none	Fill 3/4 full	Daily by overnight carrier	5-gallon bucket
	- Specific Gravity	One 8-oz wide mouth glass jars	none	none	Fill 3/4 full	Daily by overnight carrier	in cans with vermiculite
	- Water Content	One 8-oz wide mouth glass jars	none	none	Fill 3/4 full	Daily by overnight carrier	in cans with vermiculite
Soil Medium	RAS Organics						
	- Volatiles	Two 120-ml wide mouth glass vials	none	10 days	Fill 3/4 full	Federal Express Priority 1 with restricted article	in cans with vermiculite

Table A-1. Most of samples for chemical analysis will be kept iced to 4°C for the purpose of sample preservation.

Filtered groundwater samples will be submitted for metal analysis. Filtering will occur in the field immediately after sample collection. The filtering procedures is included in Appendix H of the August 1987 QAPP. Samples will be filtered through 0.45 micron filter paper using a pressure filtration device. All filtered samples will be preserved appropriately after filtration.

SAMPLING TEAM MEMBERS AND SCHEDULE

The following responsibilities have been assigned for the field sampling activities:

- o SMO Contact
Carol Shaffer/U.S. EPA
- o Site Manager (SM)
Alpheus Sloan/CH2M HILL
- o Sample Team Leader
Jeff Keiser/CH2M HILL

The remaining sampling team members will be from CH2M HILL or associate firms.

Fieldwork activities are scheduled to begin in March 1988 and last for approximately 4 weeks. The CPMS/CRL will be notified approximately 1 month prior to initiation of sample collection activities. The SMO will be notified from the CPMS/CRL for sample collection and activities.

SAMPLING DOCUMENTATION

See the Sampling Plan of the August 1987 QAPP.

WASTE DISPOSAL

Waste generated during the Predesign Investigation are expected to consist of excess soil from subsurface soil sampling and drilling cuttings, water from well drilling and development, well purge water, wastes from decontamination, and protective clothing. These wastes with HNu and OVA readings above background will be collected in Department of Transportation (DOT) approved 55-gallon drums. The 55-gallon drums will be labeled and temporarily stored onsite for later disposal, if considered necessary by EPA.

Appendix A
Attachment A-1
HAZARDOUS SUBSTANCE LIST (HSL)
AND CONTRACT REQUIRED DETECTION LIMITS (CRDL)

Hazardous Substance List (HSL) and
Contract Required Detection Limits (CRDL) **

Volatiles	CAS No.	<u>Detection Limits*</u>	
		^a	
		<u>Low Water</u>	<u>Low Soil/Sediment</u> ^b
		ug/L	ug/Kg
1. Chloromethane	74-87-3	10	10
2. Bromomethane	74-83-9	10	10
3. Vinyl Chloride	75-01-4	10	10
4. Chloroethane	75-00-3	10	10
5. Methylene Chloride	75-09-2	5	5
6. Acetone	67-64-1	10	10
7. Carbon Disulfide	75-15-0	5	5
8. 1,1-Dichloroethene	75-35-4	5	5
9. 1,1-Dichloroethane	75-35-3	5	5
10. trans-1,2-Dichloroethene	156-60-5	5	5
11. Chloroform	67-66-3	5	5
12. 1,2-Dichloroethane	107-06-2	5	5
13. 2-Butanone	78-93-3	10	10
14. 1,1,1-Trichloroethane	71-55-6	5	5
15. Carbon Tetrachloride	56-23-5	5	5
16. Vinyl Acetate	108-05-4	10	10
17. Bromodichloromethane	75-27-4	5	5
18. 1,1,2,2-Tetrachloroethane	79-34-5	5	5
19. 1,2-Dichloropropane	78-87-5	5	5
20. trans-1,3-Dichloropropene	10061-02-6	5	5
21. Trichloroethene	79-01-6	5	5
22. Dibromochloromethane	124-48-1	5	5
23. 1,1,2-Trichloroethane	79-00-5	5	5
24. Benzene	71-43-2	5	5
25. cis-1,3-Dichloropropene	10061-01-5	5	5

(continued)

Volatiles	CAS No.	Detection Limits*	
		Low Water ^a	Low Soil/Sediment ^b
		ug/L	ug/Kg
26. 2-Chloroethyl Vinyl Ether	110-75-8	10	10
27. Bromoform	75-25-2	5	5
28. 2-Hexanone	591-78-6	10	10
29. 4-Methyl-2-pentanone	108-10-1	10	10
30. Tetrachloroethene	127-18-4	5	5
31. Toluene	108-88-3	5	5
32. Chlorobenzene	108-90-7	5	5
33. Ethyl Benzene	100-41-4	5	5
34. Styrene	100-42-5	5	5
35. Total Xylenes		5	5

^a
Medium Water Contract Required Detection Limits (CRDL) for Volatile HSL Compounds are 100 times the individual Low Water CRDL.

^b
Medium Soil/Sediment Contract Required Detection Limits (CRDL) for Volatile HSL Compounds are 100 times the individual Low Soil/Sediment CRDL.

(continued)

Semi-Volatiles	CAS No.	Detection Limits*	
		^c	
		Low Water	Low Soil/Sediment ^d
		ug/L	ug/Kg
36. Phenol	108-95-2	10	330
37. bis(2-Chloroethyl) ether	111-44-4	10	330
38. 2-Chlorophenol	95-57-8	10	330
39. 1,3-Dichlorobenzene	541-73-1	10	330
40. 1,4-Dichlorobenzene	106-46-7	10	330
41. Benzyl Alcohol	100-51-6	10	330
42. 1,2-Dichlorobenzene	95-50-1	10	330
43. 2-Methylphenol	95-48-7	10	330
44. bis (2-Chloroisopropyl) ether	39638-32-9	10	330
45. 4-Methylphenol	106-44-5	10	330
46. N-Nitroso-Dipropylamine	621-64-7	10	330
47. Hexachloroethane	67-72-1	10	330
48. Nitrobenzene	98-95-3	10	330
49. Isophorone	78-59-1	10	330
50. 2-Nitrophenol	88-75-5	10	330
51. 2,4-Dimethylphenol	105-67-9	10	330
52. Benzoic Acid	65-85-0	50	1600
53. bis(2-Chloroethoxy) methane	111-91-1	10	330
54. 2,4-Dichlorophenol	120-83-2	10	330
55. 1,2,4-Trichlorobenzene	120-82-1	10	330
56. Naphthalene	91-20-3	10	330
57. 4-Chloroaniline	106-47-8	10	330
58. Hexachlorobutadiene	87-68-3	10	330
59. 4-Chloro-3-methylphenol (para-chloro-meta-cresol)	59-50-7	10	330
60. 2-Methylnaphthalene	91-57-6	10	330
61. Hexachlorocyclo- pentadiene	77-47-4	10	330
62. 2,4,6-Trichlorophenol	88-06-2	10	330
63. 2,4,5-Trichlorophenol	95-95-4	50	1600

(continued)

Semi-Volatiles	CAS No.	Detection Limits*	
		^c Low Water ug/L	^d Low Soil/Sediment ug/Kg
64. 2-Chloronaphthalene	91-58-7	10	330
65. 2-Nitroaniline	88-74-4	50	1600
66. Dimethyl Phthalate	131-11-3	10	330
67. Acenaphthylene	208-96-8	10	330
68. 3-Nitroaniline	99-09-2	50	1600
69. Acenaphthene	83-32-9	10	330
70. 2,4-Dinitrophenol	51-28-5	50	1600
71. 4-Nitrophenol	100-02-7	50	1600
72. Dibenzofuran	132-64-9	10	330
73. 2,4-Dinitrotoluene	121-14-2	10	330
74. 2,6-Dinitrotoluene	606-20-2	10	330
75. Diethylphthalate	84-66-2	10	330
76. 4-Chlorophenyl Phenyl ether	7005-72-3	10	330
77. Fluorene	86-73-7	10	330
78. 4-Nitroaniline	100-01-6	50	1600
79. 4,6-Dinitro-2-methyl- phenol	534-52-1	50	1600
80. N-nitrosodiphenylamine	86-30-6	10	330
81. 4-Bromophenyl Phenyl ether	101-55-3	10	330
82. Hexachlorobenzene	118-74-1	10	330
83. Pentachlorophenol	87-86-5	50	1600
84. Phenanthrene	85-01-8	10	330
85. Anthracene	120-12-7	10	330
86. Di-n-butylphthalate	84-74-2	10	330
87. Fluoranthene	206-44-0	10	330
88. Pyrene	129-00-0	10	330
89. Butyl Benzyl Phthalate	85-68-7	10	330
90. 3,3-Dichlorobenzidine	91-94-1	20	660
91. Benzo (a)anthracene	56-55-3	10	330
92. bis(2-ethylhexyl) phthalate	117-81-7	10	330

(continued)

<u>Detection Limits*</u>			
^c			
		<u>Low Water</u>	<u>Low Soil/Sediment</u> ^d
<u>Semi-Volatiles</u>	<u>CAS No.</u>	<u>ug/L</u>	<u>ug/Kg</u>
93. Chrysene	218-01-9	10	330
94. Di-n-octyl Phthalate	117-84-0	10	330
95. Benzo(b)fluoranthene	205-99-2	10	330
96. Benzo(k)fluoranthene	207-08-9	10	330
97. Benzo(a)pyrene	50-32-8	10	330
98. Indeno(1,2,3-cd) pyrene	193-39-5	10	330
99. Dibenz(a,h) anthracene	53-70-3	10	330
100. Benzo(g,h,i)perylene	191-24-2	10	330

^c
Medium Water Contract Required Detection Limits (CRDL) for Semi-Volatile HSL Compounds are 100 times the individual Low Water CRDL.

^d
Medium Soil/Sediment Contract Required Detection Limits (CRDL) for Semi-Volatile HSL Compounds are 60 times the individual Low Soil/Sediment CRDL.

Compound

Required Detection
Limits (CRDL) - ug/l

Metals:

1. Aluminum	200
2. Antimony	60
3. Arsenic	10
4. Barium	200
5. Beryllium	5
6. Cadmium	5
7. Calcium	5000
8. Chromium	10
9. Cobalt	50
10. Copper	25
11. Iron	100
12. Lead	5
13. Magnesium	5000
14. Manganese	15
15. Mercury	0.2
16. Nickel	40
17. Potassium	5000
18. Selenium	5
19. Silver	10
20. Sodium	5000
21. Thallium	10
22. Vanadium	50
23. Zinc	20

Appendix B
SPECIAL ANALYTICAL SERVICES (SAS)

Attachment B-1: SAS for Water Samples

Attachment B-2: SAS for Quick Turnaround Results

Attachment B-3: SAS for High Hazard Protocols

Attachment B-4: SAS for Low Detection Limits

Attachment B-5: SAS for Geotechnical Parameters

Appendix B
Attachment B-1
SPECIAL ANALYTICAL SERVICES FOR WATER SAMPLES
(COD, ALKALINITY, CHLORIDES, TSS, TDS)

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490

SAS Number
[]

SPECIAL ANALYTICAL SERVICES
Regional Request

☒ Regional Transmittal

☐ Telephone Request

A. EPA Region and Site Name: Region V, NSL/ECC

B. Regional Representative: Dennis Wesolowski

C. Telephone Number: (312) 886-1971

D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested:

Analyses for COD, TSS, TDS, Alkalinity, and chloride. The analyses will be performed by the Indiana State Board of Health. This SAS request is being filled out to help document the analytical protocols used. The analytical protocols of the ISBH are attached in Appendix D of the QAPP submitted to the U.S. EPA, August 1987.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or Soil and sediments; and whether low, medium, or high concentrations):

Analyze 20 low level groundwater samples for the parameters listed above. All samples will be unfiltered.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, ETC.):

Enforcement, Predesign Investigations

4. Estimated date(s) of collection:

5. Estimated date(s) and method of shipment: Daily by Overnight Carrier

6. Approximate number of days results required after lab receipt of samples:

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ISBH Low level spectrophotometric method attached for COD concentrations less than 50 mg/l. ISBH Mid level spectrophotometric method attached for COD concentrations greater than 50 mg/l. Samples will be preserved in the field with 2 ml of 1:1 sulfuric acid.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use potassium acid phthalate for the spike. Holding time is not to exceed 28 days from date of collection. The low level method will be used for COD concentrations less than 50 mg/l and the mid level method will be used for COD concentrations greater than 50 mg/l. Separate QC audits will be performed for each method if both are used. Dilute and rerun samples with absorbances higher than the highest standard.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Test procedures used will be clearly identified. Bench records tabulating the order of calibration standards, label control standards, lab blanks, samples, etc. with resulting absorbance or concentration readouts will be provided along with copies of work sheets used to calculate results. All records of analysis and calculations must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: (414) 272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

Parameter	Detection Limit	Precision Desired (+/- % or conc.)
<u>COD low level</u>	<u>5 mg/l</u>	<u>+/- 5 mg/l</u>
<u>COD mid level</u>	<u>50 mg/l</u>	<u>+/- 10 mg/l</u>
<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>

II. QUALITY CONTROL REQUIREMENTS

Audits Required	Frequency of Audits	Limits* (+/- % or conc.)
<u>Matrix spike 1</u>	<u>2 for runs < 10</u> <u>1 per 10 for runs >10</u>	<u>80% - 120%</u>
<u>Duplicate</u>	<u>2 for runs < 10</u> <u>1 per 10 for runs >10</u>	<u>10% or 5 mg/l</u>
<u>EPA QC Demand Reference</u> <u>Samples 2</u> <u>1 set of 2 ampules</u>	<u>1 per this project</u>	<u>80% - 120% recovery</u>

III. *Action Required if Limits are Exceeded:

Contact Chuck Elly at EPA Region V CPSPM (phone (312) 353-9087)

1. Matrix spike will provide COD greater than 30% of the sample COD but will not exceed the working range.
2. Both the low and high level QC Demand samples will be run with the low level method but only the high level sample must be run with the high level test.

6. Approximate number of days results required after lab receipt of samples:

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

See attached method. ISBH Code No. SNF-A-3-74 using glass fiber filter discs without organic binder such as Millipore AP-40, Reeves Angel 934-AH, Gelman A/E, or equivalent. Membrane filter apparatus using 47mm diameter glass fiber filter and coarse (40-60) micron fritted disc as filter support must be used. The filter and support specifications are mandatory. Sample will be collected in a one liter bottle and must be kept at 4 o C until data are validated. Holding time is 7 days from date of collection.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

1. Do not filter more than a 200 ml sample aliquot.
2. Duplicate sample aliquots will be filtered with two or more intervening samples
3. Aliquot filtered should provide residue greater than 1.0 mg for aliquots less than 200 ml.
4. Residues are to be weighed to constant weight pursuant to Part 7.1 Method 160. Final weight is to be used for calculations.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Bench records of tare weights, final weights, volumes filtered, order of blanks, duplicates, samples filtered will be provided along with copies of worksheets used to calculate results. Specify manufacturer type and diameter (mm) of glass fiber filter used. All records of analysis and calculations must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: (414) 272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

Parameter

Precision Desired

Suspended Solids

<0.5 mg for duplicates

Audits Required

Limits*

Lab Duplicate

+/- 0.5 mg

Lab Blank

1 per run and 1 per
10 samples

 $\pm 0.5 \text{ mg}$

EPA QC Residue Reference 1 per this project
1 set of 2 samples

5 mg/l for nominal
conc.

Contact Chuck Elly at EPA Region V CPMS (phone (312) 353-9087)

6. Approximate number of days results required after lab receipt of samples:

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ISBH Code No. SF-A-3-74

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use aliquots of 100 ml; however do not use sample aliquots yielding more than 200 mg of residue. Repeat analysis if residue is greater than 200 mg, using smaller aliquot. If pH is less than 4.0, raise pH value of aliquot to between pH 4 and 8 using NaOH. Subtract the weight of the sodium added from the weight of the residue. Samples will be kept at 4 °C until analysis and validation of results. For TDS, the holding time is 48 hours. Contact CPMS, CRL prior to use of any other kind of method.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Test procedure used will be clearly identified. Bench records tabulating weights used for calculations and to determine constant weight will be provided along with copies of work sheets used to calculate TDS results. All records and calculations must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: (414) 272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

Parameter

Precision Desired

Dissolved solids

10 mg/l

+/- 10 % for
duplicates or 2 mg/l
for values > 200 mg/l

Audits Required

Limits*

Lab Duplicate

1 per run and 1 per
10 samples

+/- 10 mg/l

Lab Blank

1 per run and 1 per
10 samples

+/- 2 mg/l or 10%

EPA QC Mineral Reference 1 per this project
set of 2 samples

85% - 115% recovery

Contact Chuck Elly at EPA Region V CPMS (phone (312) 353-9087)

6. Approximate number of days results required after lab receipt of samples:

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ISBH Code No. Alk-B-11-81

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Samples should be stored at 4 °C until analysis and validation of results. Sample holding time should not exceed 7 days from date of collection. Use potentiometric titration to pH 4.5 for alkalinity concentrations equal to or greater than 20 mg/l as CaCO₃. Do not use titrant volumes greater than 50 ml. Use only the method specified above. Obtain approval of CPMs, CRL prior to use of any other method.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Test procedures used will be clearly identified. Bench records tabulating the order of titrant standardization, lab blanks, samples, lab control standard, spikes, duplicates, etc. with resulting titrant volume or titrant readouts will be provided along with copies of work sheets used to calculate results. All records of analysis and calculations must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: (414) 272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

Parameter	Detection Limit	Precision Desired (+/- % or conc.)
Alkalinity	3 mg/l for low level and 20 mg/l high level	+/- 10% for >20 mg/l CaCO ₃ and +/- 2 mg/l CaCO ₃ for <20 mg/l CaCO ₃

II. QUALITY CONTROL REQUIREMENTS

Audits Required	Frequency of Audits	Limits* (+/- % or conc.)
<u>Sample spike</u>	<u>1 per run and 1 per</u> <u>20 samples</u>	<u>85% - 115% recovery</u>
<u>Lab Duplicate</u>	<u>1 per run and 1 per</u> <u>10 samples</u>	<u>+/-10% for high level</u>
<u>Lab Blank</u>	<u>1 per run and 1 per</u> <u>10 samples</u>	<u><5 mg/l for high</u> <u>level</u> <u><2 mg/l for low</u> <u>level</u>
<u>EPA QC Demand Reference</u> <u>1 set of 2 ampules</u>	<u>1 per this project</u>	<u>80% - 115% recovery</u>
<u>Titrant standardization</u>	<u>once each week</u>	

III. *Action Required if Limits are Exceeded:

Contact Chuck Elly at EPA Region V CPMS (phone (312) 353-9087)

6. Approximate number of days results required after lab receipt of samples:

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ISBH Code No. C1-C-6-79

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Sample will be kept at 4 C until analysis and validation of results. Dilute and rerun samples with absorbances higher than the highest standard. The holding time is not to exceed 28 days from the date of sample collection. Standards will be prepared daily from the stock solution. Automated potentiometric titrators can be used for Standard Methods 407c. A minimum 5 point standard curve should be used (0 to 4 standards). Use only method specified above. Obtain approval of CPMS, CRL, prior to use of any other method. Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Identify the method used. Bench records tabulating the order of titrant standardization, lab blanks, duplicates, samples, spikes, etc., with resulting titrant volumes or absorbance readings will be provided along with copies of worksheets used to calculate results. All records of analysis and calculations must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: (414) 272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

CHLORIDES - page 3

I. DATA REQUIREMENTS

Parameter	Detection Limit	Precision Desired (+/- % or conc.)
<u>Chlorides</u>	<u>1 mg/l</u>	<u>+/- 10 % or within 1 mg/l for conc. < 10 mg/l results to be reported to the nearest 1 mg/l and to 2 significant figures for conc. exceeding 10 mg/l</u>

II. QUALITY CONTROL REQUIREMENTS

Audits Required	Frequency of Audits	Limits* (+/- % or conc.)
<u>Lab Duplicate</u>	<u>1 per run and 1 per 10 samples</u>	<u>10% or 3 mg/l</u>
<u>Lab Blank</u>	<u>1 per run and 1 per 10 samples</u>	<u>< 3 mg/l</u>
<u>EPA QC Mineral ref. samples, 1 set of 2 ampules</u>	<u>1 per this project</u>	<u>85% - 115%</u>
<u>Matrix spike 1</u>	<u>1 per run and 1 per 10 samples</u>	<u>85% - 115% recovery</u>
<u>Calibration verification check sample</u>	<u>1 per 10 samples and beginning of each run</u>	<u>90 % - 110 %</u>

III. *Action Required if Limits are Exceeded:

Contact Jay Thakkar or Chuck Elly at the Region V CRL if limits are not met after reanalyzing the sample.

1. Sample spike concentration will be greater than 30% of the sample concentration, but spiked sample will not exceed the working range of the standard curve.1

Appendix B
Attachment B-2
SPECIAL ANALYTICAL SERVICES (SAS) FOR
QUICK TURNAROUND RESULTS OF
RAS METALS AND ORGANICS

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

**SPECIAL ANALYTICAL SERVICES
Regional Request**

☐

Regional Transmittal

☐

Telephone Request

- A. EPA Region and Site Name: Region V, NSL/ECC
- B. Regional Representative: Dennis Wesolowski
- C. Telephone Number: (312) 886-1971
- D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____
Quick turnaround organics analysis for 23 soil samples for VOCs and A,B/N extractables,
consistent with RAS protocol.
2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):
23 Total soil samples--Low concentration organics.
3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):
Enforcement, Predesign Investigations
4. Estimated date(s) of collection: _____
5. Estimated date(s) and method of shipment: Daily by overnight carrier

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Same as IFB

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Same as IFB

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Same as IFB

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> ($\pm\%$ or Conc.)
Same as IFB	Same as IFB	Same as IFB

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* ($\pm\%$ or Conc.)</u>
Same as IFB	Same as IFB	Same as IFB

III. *Action Required if Limits are Exceeded:

Same as IFB

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

**SPECIAL ANALYTICAL SERVICES
Regional Request**

☐

Regional Transmittal

☐

Telephone Request

A. EPA Region and Site Name: Region V, NSL/ECC

B. Regional Representative: Dennis Wesolowski

C. Telephone Number: (312) 886-1971

D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Quick turnaround inorganics analysis for 23 soil samples for metals consistent with
RAS protocol.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):

23 Total soil samples--Low concentration metals.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigations

4. Estimated date(s) of collection: _____

5. Estimated date(s) and method of shipment: Daily by overnight carrier

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Same as IFB

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Same as IFB

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Same as IFB

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (±% or Conc.)
Same as IFB	Same as IFB	Same as IFB

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (±% or Conc.)</u>
Same as IFB	Same as IFB	Same as IFB

III. *Action Required if Limits are Exceeded:

Same as IFB

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

**SPECIAL ANALYTICAL SERVICES
Regional Request**

☐

Regional Transmittal

☐

Telephone Request

- A. EPA Region and Site Name: Region V, NSL/ECC
- B. Regional Representative: Dennis Wesolowski
- C. Telephone Number: (312) 886-1971
- D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Quick turnaround organics analysis for 20 water samples for VOCs and A,B/N extractables,
consistent with RAS protocol.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):

20 Total groundwater samples--low concentration organics. Unfiltered samples will be
analyzed.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigation

4. Estimated date(s) of collection: _____

5. Estimated date(s) and method of shipment: Daily by overnight carrier

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Same as IFB

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Same as IFB

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Same as IFB

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> ($\pm\%$ or Conc.)
Same as IFB	Same as IFB	Same as IFB

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits*</u> ($\pm\%$ or Conc.)
Same as IFB	Same as IFB	Same as IFB

III. *Action Required if Limits are Exceeded:

Same as IFB

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

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Telephone Request

A. EPA Region and Site Name: Region V, NSL/ECC

B. Regional Representative: Dennis Wesolowski

C. Telephone Number: (312) 886-1971

D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Quick turnaround inorganics analysis for 20 water samples for metals consistent
with RAS protocol.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):

Twenty total groundwater samples--Low concentration metals. Filtered samples
will be analyzed.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigations

4. Estimated date(s) of collection: _____

5. Estimated date(s) and method of shipment: Daily by overnight carrier.

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Same as IFB

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Same as IFB

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Same as IFB

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (\pm % or Conc.)
Same as IFB	Same as IFB	Same as IFB

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits*</u> (\pm % or Conc.)
Same as IFB	Same as IFB	Same as IFB

III. *Action Required if Limits are Exceeded:

Same as IFB

Appendix B

Attachment B-3

SAS FOR HIGH HAZARD PROTOCOLS FOR WATER HSL VOLATILES

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

**SPECIAL ANALYTICAL SERVICES
Regional Request**

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Regional Transmittal

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Telephone Request

- A. EPA Region and Site Name: Region V, NSL/ECC
- B. Regional Representative: Dennis Wesolowski
- C. Telephone Number: (312) 886-1971
- D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Analyze groundwater samples for HSL volatiles using the High Hazard analytical protocol.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):

Analyze 12 groundwater samples for HSL VOCs using the High Hazard Protocol.

The samples will be medium concentration.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigation

4. Estimated date(s) of collection: _____

5. Estimated date(s) and method of shipment: Daily by overnight carrier

6. Approximate number of days results required after lab receipt of samples: _____

Report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

As specified in proposed U.S. EPA protocol for analysis of high/medium concentration organics (Rev. 4/85).

8. Special technical instructions (If outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Medium concentrations are anticipated for some samples.

9. Analytical results required (If known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Provide deliverables as per proposed U.S. EPA protocol for Analysis of high/medium concentration organics (Rev. 4/85). Document sample preparation cleanup and analysis.

Report all QA/QC. All records must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (% or Conc.)
HSL volatiles	As per U.S. EPA proposed	
	protocol for high/medium	
	organics analysis	
	(Rev. 4/85)	

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (% or Conc.)</u>
As per U.S. EPA proposed protocol for high/medium organics analysis (Rev. 4/85).		

III. *Action Required if Limits are Exceeded:

Contact Chuck Elly 312/353-9087.

Appendix B

Attachment B-4
SAS FOR LOW DETECTION LIMITS
FOR GROUNDWATER VOCs

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

**SPECIAL ANALYTICAL SERVICES
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Regional Transmittal

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Telephone Request

- A. EPA Region and Site Name: Region V, NSL/ECC
- B. Regional Representative: Dennis Wesolowski
- C. Telephone Number: (312) 886-1971
- D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Analyze groundwater for low levels of VOCs.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration):

Analyze 20 groundwater samples for the low level volatiles listed in Table 1 of the attachment (Method 524.2) immediately following this SAS

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigation

4. Estimated date(s) of collection: _____
5. Estimated date(s) and method of shipment: _____

6. Approximate number of days results required after lab receipt of samples: _____

The laboratory will report results within 30 days after receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Method 524.2 attached (Attachment 1)

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Qualitatively identify the compounds of interest listed in Table 1. Use all compounds of interest for matrix spike and matrix spike duplicate analysis. Use 1,2-Dichloroethane-d4 and benzene-d8 for surrogate compounds. Matrix spikes and surrogates will be spiked at 0.4 ug/l. See 10 below.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Report results of all samples, blanks, matrix spikes, matrix spike duplicates and surrogates, etc., including copies of mass spectra, initial and continuing calibration, chromatograms, etc. All copies must be legible.

10. Other (use additional sheets or attach supplementary information, as needed):

Use only the narrow bore capillary column for analysis. Obtain prior approval of CPMS CRL before using any alternate methods.

11. Name of sampling/shipping contact: Jeff Keiser

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (±% or Conc.)
Low Level VOAs	Table 1	+ 30%

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (±% or Conc.)</u>
Laboratory Blanks	At least one per analytical run and 1 per 10 samples	Detection Limits
Matrix Spikes	At least one per analytical run and 1 per 10 samples	70-130%
Matrix Spike Duplicates	At least one per analytical run and 1 per 10 samples	70-130%
Surrogates	Each Samples	60-140%
QC Check Sample	1 per this project	60-140%

III. *Action Required if Limits are Exceeded:

Contact Dennis Wesolowski at U.S. EPA Region V CRL

Attachment 1

METHOD 524.2. VOLATILE ORGANIC COMPOUNDS IN WATER BY
PURGE AND TRAP CAPILLARY COLUMN GAS CHROMATOGRAPHY/MASS SPECTROMETRY
(August, 1986)

1. SCOPE AND APPLICATION

- 1.1 This method is applicable for the determination of various volatile organic compounds in finished drinking water, raw source water, or drinking water in any treatment stage. (1) The following compounds can be determined by this method:

<u>Analyte</u>	<u>Chemical Abstract Services Registry Number</u>
Benzene	71-43-2
Bromobenzene	108-86-1
Bromochloromethane	74-97-5
Bromodichloromethane	75-27-4
Bromoform	75-25-2
Bromomethane	74-83-9
n-Butylbenzene	104-51-8
sec-Butylbenzene	135-98-8
tert-Butylbenzene	98-06-6
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroethane	75-00-3
Chloroform	67-66-3
Chloromethane	74-87-3
2-Chlorotoluene	95-49-8
4-Chlorotoluene	106-43-4
Dibromochloromethane	124-48-1
1,2-Dibromo-3-chloropropane	96-12-8
1,2-Dibromoethane	106-93-4
Dibromomethane	74-95-3
1,2-Dichlorobenzene	95-50-1
1,3-Dichlorobenzene	541-73-1
1,4-Dichlorobenzene	106-46-7
Dichlorodifluoromethane	75-71-8
1,1-Dichloroethane	75-34-3
1,2-Dichloroethane	107-06-2
1,1-Dichloroethene	75-35-4
cis-1,2-Dichloroethene	156-59-4

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Analyte

Chemical Abstract Services
Registry Number

trans-1,2-Dichloroethene	156-60-5
1,2-Dichloropropane	78-87-5
1,3-Dichloropropane	142-28-9
2,2-Dichloropropane	590-20-7
1,1-Dichloropropene	563-58-6
Ethylbenzene	100-41-4
Hexachlorobutadiene	87-68-3
Isopropylbenzene	98-82-8
p-Isopropyltoluene	99-87-6
Methylene chloride	75-09-2
Naphthalene	91-20-3
n-Propylbenzene	103-65-1
Styrene	100-42-5
1,1,1,2-Tetrachloroethane	630-20-6
1,1,2,2-Tetrachloroethane	79-34-5
Tetrachloroethene	127-18-4
Toluene	108-88-3
1,2,3-Trichlorobenzene	87-61-6
1,2,4-Trichlorobenzene	120-82-1
1,1,1-Trichloroethane	71-55-6
1,1,2-Trichloroethane	79-00-5
Trichloroethene	79-01-6
Trichlorofluoromethane	75-69-4
1,2,3-Trichloropropane	96-18-4
1,2,4-Trimethylbenzene	95-63-6
1,3,5-Trimethylbenzene	108-67-8
Vinyl chloride	75-01-4
o-Xylene	95-47-6
m-Xylene	108-38-3
p-Xylene	106-42-3

- 1.2 Method detection limits (MDLs) (2) are compound dependent and vary with purging efficiency and concentration. The MDLs for selected analytes are presented in Table 1. The applicable concentration range of this method is compound and instrument dependent but is approximately 0.1 to 200 µg/L. Analytes that are inefficiently purged from water will not be detected when present at low concentrations, but they can be measured with acceptable accuracy and precision when present in sufficient amounts. Determination of some geometrical isomers (i.e., xylenes) may be hampered by coelution.

- 1.3 This method is recommended for use only by analysts experienced in the measurement of purgeable organics at the low $\mu\text{g/L}$ level or by experienced technicians under the close supervision of a qualified analyst.

2. SUMMARY OF METHOD

- 2.1 Highly volatile organic compounds with low water solubility are extracted (purged) from the sample matrix by bubbling an inert gas through a 25 mL aqueous sample. Purged sample components are trapped in a tube containing suitable sorbent materials. When purging is complete, the sorbent tube is heated and backflushed with helium to desorb trapped sample components. The analytes are desorbed directly to a large bore capillary or cryofocussed on a capillary precolumn before being flash evaporated to a narrow bore capillary for analysis. The column is temperature programmed to separate the method analytes which are then detected with a mass spectrometer (MS) interfaced to the gas chromatograph.

Wide-bore capillary columns generally require a jet separator, whereas narrow-bore capillaries can be directly interfaced to the ion source.

- 2.2 Tentative identifications are confirmed by analyzing standards under the same conditions used for samples and comparing resultant mass spectra and GC retention times. Each identified component is measured by relating the MS response for an appropriate selected ion produced by that compound to the MS response for another ion produced by a compound that is used as an internal standard.

3. INTERFERENCES

- 3.1 During analysis, major contaminant sources are volatile materials in the laboratory and impurities in the inert purging gas and in the sorbent trap. The use of non-polytetrafluoroethylene (PTFE) plastic tubing, non-PTFE thread sealants, or flow controllers with rubber components in the purging device should be avoided since such materials out-gas organic compounds which will be concentrated in the trap during the purge operation. Analyses of laboratory reagent blanks (Sect. 9.1.3) provide information about the presence of contaminants. When potential interfering peaks are noted in laboratory reagent blanks, the analyst should change the purge gas source and regenerate the molecular sieve purge gas filter (Fig. 1). Subtracting blank values from sample results is not permitted.

3.2 Interfering contamination may occur when a sample containing low concentrations of volatile organic compounds is analyzed immediately after a sample containing relatively high concentrations of volatile organic compounds. A preventive technique is between-sample rinsing of the purging apparatus and sample syringes with two portions of reagent water. After analysis of a sample containing high concentrations of volatile organic compounds, one or more laboratory reagent blanks should be analyzed to check for cross contamination. For samples containing large amounts of water soluble materials, suspended solids, high boiling compounds or high levels of compounds being determined, it may be necessary to wash out the purging device with a soap solution, rinse it with reagent water, and then dry it in an oven at 105°C between analyses.

3.3 Special precautions must be taken to analyze for methylene chloride. The analytical and sample storage area should be isolated from all atmospheric sources of methylene chloride, otherwise random background levels will result. Since methylene chloride will permeate through PTFE tubing, all gas chromatography carrier gas lines and purge gas plumbing should be constructed from stainless steel or copper tubing. Laboratory clothing worn by the analyst should be clean since clothing previously exposed to methylene chloride fumes during common liquid/liquid extraction procedures can contribute to sample contamination.

4. SAFETY

4.1 The toxicity or carcinogenicity of chemicals used in this method has not been precisely defined; each chemical should be treated as a potential health hazard, and exposure to these chemicals should be minimized. Each laboratory is responsible for maintaining awareness of OSHA regulations regarding safe handling of chemicals used in this method. Additional references to laboratory safety are available (3-5) for the information of the analyst.

4.2 The following method analytes have been tentatively classified as known or suspected human or mammalian carcinogens: benzene, carbon tetrachloride, 1,4-dichlorobenzene, 1,2-dichloroethane, hexachlorobutadiene, 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, chloroform, 1,2-dibromoethane, tetrachloroethene, trichloroethene, and vinyl chloride. Pure standard materials and stock standard solutions of these compounds should be handled in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. APPARATUS AND EQUIPMENT

- 5.1 **SAMPLE CONTAINERS** - 60-mL to 120-mL screw cap vials (Pierce #19832 or equivalent) each equipped with a PTFE-faced silicone septum (Pierce #12718 or equivalent). Prior to use, wash vials and septa with detergent and rinse with tap and distilled water. Allow the vials and septa to air dry at room temperature, place in a 105°C oven for one hour, then remove and allow to cool in an area known to be free of organics.
- 5.2 **PURGE AND TRAP SYSTEM** - The purge and trap system consists of three separate pieces of equipment: purging device, trap, and desorber. Systems are commercially available from several sources that meet all of the following specifications.
 - 5.2.1 The all glass purging device (Fig. 1) must be designed to accept 25-mL samples with a water column at least 5 cm deep. Gaseous volumes above the sample must be kept to a minimum (< 15 mL) to eliminate dead volume effects. A glass frit should be installed at the base of the sample chamber so the purge gas passes through the water column as finely divided bubbles with a diameter of < 3 mm at the origin. Needle spargers may be used, however, the purge gas must be introduced at a point \leq 5 mm from the base of the water column.
 - 5.2.2 The trap (Fig. 2) must be at least 25 cm long and have an inside diameter of at least 0.105 in. Starting from the inlet, the trap should contain 1.0 cm of methyl silicone coated packing and the following amounts of adsorbents: 1/3 of 2,6-diphenylene oxide polymer, 1/3 of silica gel, and 1/3 of coconut charcoal. Before initial use, the trap should be conditioned overnight at 180°C by backflushing with an inert gas flow of at least 20 mL/min. Vent the trap effluent to the room, not to the analytical column. Prior to daily use, the trap should be conditioned for 10 minutes at 180°C with backflushing. The trap may be vented to the analytical column during daily conditioning; however, the column must be run through the temperature program prior to analysis of samples.
 - 5.2.3 The use of the methyl silicone coated packing is recommended, but not mandatory. The packing serves a dual purpose of protecting the adsorbent from aerosols, and also of insuring that the adsorbent is fully enclosed within the heated zone of the trap thus eliminating potential cold spots. Alternatively, silanized glass wool may be used as a spacer at the trap inlet.

5.2.4 The desorber must be capable of rapidly heating the trap to 180°C. The polymer section of the trap should not be heated higher than 200°C or the life expectancy of the trap will decrease. Trap failure is characterized by a pressure drop in excess of 3 pounds per square inch across the trap during purging or by poor bromoform sensitivities. The desorber design illustrated in Fig. 2 meets these criteria.

5.2.5 Figures 3 and 4 show typical flow patterns for the purge-sorb and desorb modes.

5.3 GAS CHROMATOGRAPHY/MASS SPECTROMETER/DATA SYSTEM (GC/MS/DS)

5.3.1 The GC must be capable of temperature programming and should be equipped with variable-constant differential flow controllers so that the column flow rate will remain constant throughout desorption and temperature program operation. The column oven must be cooled to <30°C, therefore, a subambient oven controller is required. The GC usually is interfaced to the MS with an all-glass enrichment device and an all-glass transfer line, but any enrichment device or transfer line can be used if the performance specifications described in Sect. 9.2.5 can be achieved.

5.3.4 Gas Chromatographic Column 3 - 30 meter long x 0.32mm ID fused silica capillary column coated with Durabond DB-5 (J&W Scientific, Inc.) with a 1µm film thickness. Helium carrier gas flow is 4.0 mL/min. The column is maintained at 10°C for 5 mins, then programmed at 6°/min for 10 min then 15°/min for 5 min to 145°C. A sample chromatogram obtained with this column is presented in Fig. 7.

5.3.5 Mass spectral data are obtained with electron-impact ionization at a nominal electron energy of 70 eV. The mass spectrometer must be capable of scanning from 35 to 300 amu every 2s or less and must produce a mass spectrum that meets all criteria in Table 3 when 50 ng or less of 4-bromofluorobenzene is introduced into the GC. To ensure sufficient precision of mass spectral data, the desirable MS scan rate allows acquisition of at least five spectra while a sample component elutes from the GC.

5.3.6 An interfaced data system (DS) is required to acquire, store, reduce and output mass spectral data. The computer software must allow searching any GC/MS data file for ions of a specific mass and plotting ion abundances versus time or scan number. This type of plot is defined as an extracted ion current profile (EICP). Software must also allow integrating the abundance in any EICP between specified time or scan number limits.

5.4 CAPILLARY INTERFACE - The device interfaces the purge and trap concentrator to the capillary gas chromatograph. The interface condenses the desorbed sample components and focuses them into a narrow band on an uncoated fused silica capillary pre-column. When the interface is flash heated the sample is transferred to the analytical capillary column.

5.4.1 Under a stream of liquid nitrogen, the temperature of the fused silica in the interface is maintained at -150°C during the cryofocusing step. After the desorption period, the interface must be capable of rapid heating to $+250^{\circ}\text{C}$ in 15 sec. or less to complete the transfer of analytes.

5.5 SYRINGE AND SYRINGE VALVES

5.5.1 Two 25-mL glass hypodermic syringes with Luer-Lok tip.

5.5.2 Three 2-way syringe valves with Luer ends.

5.5.3 Micro syringes - 10, 25, 100 μL .

5.5.4 Syringes - 0.5, 1.0, and 5-mL, gas tight with shut-off valve.

5.6 MISCELLANEOUS

5.6.1 Standard solution storage containers - 15-mL bottles with PTFE-lined screw caps.

6. REAGENTS AND CONSUMABLE MATERIALS

6.1 TRAP PACKING MATERIALS

- 6.1.1 2,6-Diphenylene oxide polymer, 60/80 mesh, chromatographic grade (Tenax GC or equivalent).
- 6.1.2 Methyl silicone packing (optional) - OV-1 (3%) on Chromosorb W, 60/80 mesh, or equivalent.
- 6.1.3 Silica gel - 35/60 mesh, Davison, grade 15 or equivalent.
- 6.1.4 Coconut charcoal - Prepare from Barnebey Cheney, CA-580-26 lot #M-2649 by crushing through 26 mesh screen.

6.2 REAGENTS

- 6.2.1 Methanol - Demonstrated to be free of analytes.
- 6.2.2 Reagent water - Prepare reagent water by passing tap water through a filter bed containing about 0.5 kg of activated carbon, by using a water purification system, or by boiling distilled water for 15 min followed by a 1-h purge with inert gas while the water temperature is held at 90°C. Store in clean, narrow-mouth bottles with PTFE-lined septa and screw caps.
- 6.2.3 Hydrochloric acid (1+1) - Carefully add measured volume of conc. HCl to equal volume of reagent water.
- 6.2.4 Vinyl chloride - 99.9% pure vinyl chloride is available from Ideal Gas Products, Inc., Edison, New Jersey and from Matheson, East Rutherford, New Jersey. Certified mixtures of vinyl chloride in nitrogen at 1.0 and 10.0 ppm (v/v) are available from several sources.

6.3 STANDARD STOCK SOLUTIONS - These solutions may be purchased as certified solutions or prepared from pure standard materials using the following procedures:

- 6.3.1 Place about 9.8 mL of methanol into a 10-mL ground-glass stoppered volumetric flask. Allow the flask to stand, unstoppered, for about 10 min or until all alcohol-wetted surfaces have dried and weigh to the nearest 0.1 mg.

- 6.3.2 If the analyte is a liquid at room temperature, use a 100- μ L syringe and immediately add two or more drops of reference standard to the flask. Be sure that the reference standard falls directly into the alcohol without contacting the neck of the flask. If the analyte is a gas at room temperature, fill a 5-mL valved gas-tight syringe with the standard to the 5.0-mL mark, lower the needle to 5 mm above the methanol meniscus, and slowly inject the standard into the neck area of the flask. The gas will rapidly dissolve in the methanol.
- 6.3.3 Reweigh, dilute to volume, stopper, then mix by inverting the flask several times. Calculate the concentration in micrograms per microliter from the net gain in weight. When compound purity is certified at 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard.
- 6.3.4 Store stock standard solutions in 15-mL bottles equipped with PTFE-lined screw caps. Methanol solutions prepared from liquid analytes are stable for at least four weeks when stored at 4°C. Methanol solutions prepared from gaseous analytes are not stable for more than one week when stored at <0°C; at room temperature, they must be discarded after one day.
- 6.4 SECONDARY DILUTION STANDARDS - Use standard stock solutions to prepare secondary dilution standard solutions that contain the analytes in methanol. The secondary dilution standards should be prepared at concentrations that can be easily diluted to prepare aqueous calibration solutions (Sect. 8.1) that will bracket the working concentration range. Store the secondary dilution standard solutions with minimal headspace and check frequently for signs of deterioration or evaporation, especially just before preparing calibration solutions from them. Storage times described for stock standard solutions in Sect. 6.3.4 also apply to secondary dilution standard solutions.
- 6.5 INTERNAL STANDARD SPIKING SOLUTION - Prepare a spiking solution containing fluorobenzene, and 1,2-dichlorobenzene- d_4 in methanol using the procedures described in Sect. 6.3 and 6.4. It is recommended that the secondary dilution standard be prepared at a concentration of 25 μ g/mL of each internal standard compound. The addition of 10 μ L of such a standard to 25.0 mL of sample or calibration standard would be equivalent to 10 μ g/L.
- 6.6 BFB STANDARD - Prepare a 25- μ g/mL solution of bromofluorobenzene in methanol.

6.7 LABORATORY QUALITY CONTROL STANDARD CONCENTRATE - Using standard stock solutions, prepare a solution containing each analyte of interest at a concentration of 500 times the MCL in methanol.

7. SAMPLE COLLECTION, PRESERVATION, AND STORAGE

7.1 SAMPLE COLLECTION

- 7.1.1 Collect all samples in duplicate. Fill sample bottles to overflowing. No air bubbles should pass through the sample as the bottle is filled, or be trapped in the sample when the bottle is sealed.
- 7.1.2 When sampling from a water tap, open the tap and allow the system to flush until the water temperature has stabilized (usually about 10 min). Adjust the flow to about 500 mL/min and collect duplicate samples from the flowing stream.
- 7.1.3 When sampling from an open body of water, fill a 1-quart wide-mouth bottle or 1-liter beaker with sample from a representative area, and carefully fill duplicate sample bottles from the container.

7.2 SAMPLE PRESERVATION

- 7.2.1 Adjust the pH of the duplicate samples to <2 by carefully adding one drop of 1:1 HCl for each 20 mL of sample volume.(6) Seal the sample bottles, PTFE-face down, and shake vigorously for one minute.
- 7.2.2 The samples must be chilled to 4°C on the day of collection and maintained at that temperature until analysis. Field samples that will not be received at the laboratory on the day of collection must be packaged for shipment with sufficient ice to ensure that they will be at 4°C on arrival at the laboratory.

7.3 SAMPLE STORAGE

- 7.3.1 Store samples at 4°C until analysis. The sample storage area must be free of organic solvent vapors.
- 7.3.2 Analyze all samples within 14 days of collection. Samples not analyzed within this period must be discarded and replaced.

8. CALIBRATION AND STANDARDIZATION

8.1 PREPARATION OF CALIBRATION STANDARDS

- 8.1.1 A set of at least five calibration standards containing the method analytes is needed. One calibration standard should contain each analyte at a concentration approaching but greater than the method detection limit (Table 1) for that compound; the other calibration standards should contain analytes at concentrations that define the range of the method.
- 8.1.2 To prepare a calibration standard, add an appropriate volume of a secondary dilution standard solution to an aliquot of reagent water in a volumetric flask. Use a microsyringe and rapidly inject the alcoholic standard into the expanded area of the filled volumetric flask. Remove the needle as quickly as possible after injection. Mix by inverting the flask three times only. Discard the contents contained in the neck of the flask. Aqueous standards are not stable and should be discarded after one hour unless sealed and stored as described in Sect. 7.2.

8.2 CALIBRATION

- 8.2.1 After meeting the BFB criteria in Sect. 10.1, analyze each calibration standard according to Sect. 10, adding 10 μ L of internal standard spiking solution directly to the syringe. For each analyte, select a significant characteristic ion. When feasible, use the most intense ion in the mass spectrum; when a less intense ion is more characteristic and sufficiently intense to provide necessary sensitivity, use that ion to avoid possible interferences. Tabulate area response of the characteristic m/z versus the concentration for each analyte and internal standard. Calculate response factors (RF) for each analyte using Equation 1:

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)} \quad \text{Equation 1}$$

where:

- A_s = Area of the characteristic m/z for the analyte to be measured;
 A_{is} = Area of the characteristic m/z for the internal standard;

C_{is} = Concentration of the internal standard, in $\mu\text{g/L}$.
 C_s = Concentration of the analyte to be measured, in $\mu\text{g/L}$.

The choice of which internal standard to use for an analyte is left to the analyst.

- 8.2.2 Prepare a calibration curve for each analyte. Alternatively, if the RF for an analyte is constant (less than 10% RSD) over the working range, the average RF can be used for that analyte.
- 8.2.3 The working calibration curve or average response factor must be verified on each working day by the measurement of one or more calibration standards. If the quantitation ion area for any analyte varies from the response determined for that standard concentration from the calibration curve or average RF established in Sect. 8.2.2 by more than $\pm 20\%$, repeat steps 8.2.1 and 8.2.2.
- 8.2.4 Calibration for vinyl chloride using a certified gaseous mixture of vinyl chloride in nitrogen can be accomplished by the following steps.
- 8.2.4.1 Fill the purging device with 25.0 mL of reagent water or aqueous calibration standard.
- 8.2.4.2 Start to purge the aqueous mixture. Inject a known volume (between 100 and 2000 μL) of the calibration gas (at room temperature) directly into the purging device with a gas tight syringe. Slowly inject the gaseous sample through a septum seal at the top of the purging device at 2000 $\mu\text{L/min}$. Do not inject the standard through the aqueous sample inlet needle. Inject the gaseous standard before five min of the 11-min purge time have elapsed.
- 8.2.4.3 Determine the aqueous equivalent concentration of vinyl chloride standard, in $\mu\text{g/L}$, injected with the equation:

$$S = 0.102 (C)(V) \quad \text{Equation 2}$$

where S = Aqueous equivalent concentration of vinyl chloride standard in $\mu\text{g/L}$;
 C = Concentration of gaseous standard in ppm;
 V = Volume of standard injected in milliliters.

9. QUALITY CONTROL

- 9.1** Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. A quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.
- 9.1.1** The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 9.2.
- 9.1.2** In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Section 10.2.2) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 9.2.
- 9.1.3** Each day, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system are under control.
- 9.1.4** The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 9.3. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but at least two samples per month.
- 9.1.5** On a weekly basis, the laboratory must demonstrate the ability to analyze low level samples. A procedure for low level check samples is described in Section 9.4.
- 9.1.6** The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 9.5.
- 9.2** To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

- 9.2.1 A quality control (QC) check sample concentrate is required containing each regulated analyte, and any additional analyte which is to be reported, at a concentration of 500 times the MCL or 5 $\mu\text{g/mL}$, whichever is smaller, in methanol. The QC check sample must be prepared by the laboratory using stock standards prepared independently from those used for calibration.
- 9.2.2 Analyze seven 25-mL QC check samples at 1/5 MCL or 2 $\mu\text{g/L}$ according to the method beginning in Sect. 10. Each sample is produced by injecting 10 μL of QC check sample concentrate into 25 mL of reagent water in a glass syringe through the syringe valve.
- 9.2.3 Calculate the average recovery (\bar{X}) in $\mu\text{g/L}$, and the standard deviation of the recovery (s) in $\mu\text{g/L}$ for each analyte using the seven results. Calculate the MDL for each analyte as specified in Ref. 2. The calculated MDL must be less than the spike level.
- 9.2.4 For each analyte, (\bar{X}) must be between 90% and 110% of the true value. Additionally, s must be $< 35\%$ of \bar{X} . If s and \bar{X} for all analytes meet the criteria, the system performance is acceptable and analysis of actual samples can begin. If any s exceeds the precision limit or any \bar{X} falls outside the range for accuracy, the system performance is unacceptable for that analyte.
NOTE: The large number of analytes present a substantial probability that one or more will fail at least one of the acceptance criteria when all analytes are analyzed.
- 9.2.5 When one or more of the analytes tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 9.2.2 only for the analytes which failed the test.
- 9.3 The laboratory must demonstrate on a regular basis as outlined in Section 9.1.4 that the measurement system is in control by analyzing a quality control check sample for all analytes of interest at the MCL or 10 $\mu\text{g/L}$, whichever is smaller.
- 9.3.1 Prepare a QC check standard by adding 50 μL of QC check sample concentrate to 25 mL of reagent water in a glass syringe.
- 9.3.2 Analyze the QC check according to Section 10, and calculate the recovery for each analyte. The recovery must be between 60% and 140% of the expected value.

- 9.3.3 If the recovery for any analyte falls outside the designated range, the analyte has failed the acceptance criteria. A check standard containing each analyte that failed must be re-analyzed.
- 9.4 On a weekly basis, the laboratory must demonstrate the ability to analyze low level samples.
- 9.4.1 Prepare a low level check sample by spiking 10 μ L of QC check sample concentrate to 25 mL of reagent water and analyze according to the method in Sect. 10.
- 9.4.2 For each analyte, the recovery must be between 60% and 140% of the expected value.
- 9.4.3 When one or more analytes fail the test, the analyst must repeat the test only for those analytes which failed to meet the criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with 9.4.1.
- 9.5 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

10. PROCEDURE

10.1 DAILY GC/MS PERFORMANCE TESTS

- 10.1.1 At the beginning of each day that analyses are to be performed, the GC/MS system must be checked to see if acceptable performance criteria are achieved for BFB (7). The performance test must be passed before any samples, blanks, or standards are analyzed.
- 10.1.2 At the beginning of each day, inject 2 μ L (50 ng) of BFB solution directly on the column. Alternatively, add 2 μ L of BFB solution to 25.0 mL of reagent water or calibration standard and analyze the solution according to Sect. 10. Obtain a background-corrected mass spectrum of BFB and confirm that all the key m/z criteria in Table 3 are achieved. If all the criteria are not achieved, the analyst must retune the mass spectrometer and repeat the test until all criteria are achieved.

10.2 INITIAL CONDITIONS

10.2.1 Acquire GC/MS data for performance tests, standards and samples using the following instrumental analytes:

Electron Energy: 70 V (nominal)
Mass Range: 35 to 300 amu
Scan Time: To give at least 5 scans per peak but not to exceed 2 s per scan.

10.2.2 The operating conditions for the gas chromatograph are summarized under Sections 5.3.2 through 5.3.4.. Tables 1 and 2 list the retention times and MDL that can be achieved under these conditions. Examples of separations achieved with this method are shown in Figures 5-7. Other columns or chromatographic conditions may be used if the requirements of Section 9 are met.

10.3 SAMPLE INTRODUCTION AND PURGING

10.3.1 Adjust the purge gas (nitrogen or helium) flow rate to 40 mL/min. Attach the trap inlet to the purging device and open the syringe valve on the purging device.

10.3.2 Remove the plungers from two 25-mL syringes and attach a closed syringe valve to each. Warm the sample to room temperature, open the sample (or standard) bottle, and carefully pour the sample into one of the syringe barrels to just short of overflowing. Replace the syringe plunger, invert the syringe, and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 25.0 mL. Add 10 μ L of the internal standard spiking solution (Section 6.5) to the sample through the syringe valve. Close the valve. Fill the second syringe in an identical manner from the same sample bottle. Reserve this second syringe for a reanalysis if necessary.

10.3.3 Attach the sample syringe valve to the syringe valve on the purging device. Be sure that the trap is cooler than 25°C, then open the sample syringe valve and inject the sample into the purging chamber. Close both valves and initiate purging. Purge the sample for 11.0 \pm 0.1 min at ambient temperature (Fig. 3).

10.4 SAMPLE DESORPTION - The mode of sample desorption is determined by the type of capillary column employed for the analysis. When using a wide-bore capillary column, follow the desorption conditions of Sect. 10.3.1. The conditions for using narrow bore columns is described in Sect. 10.3.2.

10.4.2 Sample Desorption for Narrow-Bore Capillary Column

Under normal operating conditions, most narrow-bore capillary columns can be interfaced directly to the MS without a jet separator.

10.4.2.1 Sample Desorption - After the 11 min purge, attach the trap to the cryogenically cooled interface at -150°C and adjust the purge and trap system to the desorb mode (Fig. 4). Introduce the trapped materials to the interface by rapidly heating the trap to 180°C while backflushing the trap with an

inert gas at 4 mL/min for 5.0 ± 0.1 min. While the extracted sample is being introduced into the interface, empty the purging device using the sample syringe and rinse the chamber with two 25-mL flushes of reagent water. After the purging device has been emptied, leave the syringe valve open to allow the purge gas to vent through the sample introduction needle. After desorbing for 5 min, flash heat the interface to 250°C and quickly introduce the sample on the chromatographic column. Start the temperature program sequence, and initiate data acquisition.

10.4.2.2 Gas Chromatography - Hold the column temperature at 10°C for 5 min, then program at 6°C/min to 70°C and then at 15°C/min to 145°C.

10.3.2.3 Trap Reconditioning - After desorbing the sample for 5 min, recondition the trap by returning the purge and trap system to the purge mode. Wait 15 s, then close the syringe valve on the purging device to begin gas flow through the trap. Maintain the trap temperature at 180°C. After approximately 15 min, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When the trap is cool, the next sample can be analyzed.

10.5 TERMINATION OF DATA ACQUISITION - When sample components have eluted from the GC, terminate MS data acquisition and store data files on the data system storage device. Use appropriate data output software to display full range mass spectra and appropriate EICPs. If any ion abundance exceeds the system working range, dilute the sample aliquot in the second syringe with reagent water and analyze the diluted aliquot.

11. QUALITATIVE IDENTIFICATION

11.1 IDENTIFICATION PROCEDURES CRITERIA - Tentatively identify a sample component by comparison of its mass spectrum (after background subtraction) to a reference spectrum in a collection. Use the following criteria to confirm a tentative identification:

11.1.1 The GC retention time of the sample component must be within 10 s of the time observed for that same compound when a calibration solution was analyzed.

11.1.2 All ions that are present above 10% relative abundance in the mass spectrum of the standard must be present in the

mass spectrum of the sample component and should agree within absolute 10%. For example, if an ion has a relative abundance of 30% in the standard spectrum, its abundance in the sample spectrum should be in the range of 20 to 40%.

11.1.3 Identification is hampered when sample components are not resolved chromatographically and produce mass spectra containing ions contributed by more than one analyte. Because purgeable organic compounds are relatively small molecules and produce comparatively simple mass spectra, this is not a significant problem for most method analytes. When GC peaks obviously represent more than one sample component (i.e., broadened peak with shoulder(s) or valley between two or more maxima), appropriate analyte spectra and background spectra can be selected by examining EICPs of characteristic ions for tentatively identified components. When analytes coelute (i.e., only one GC peak is apparent), the identification criteria described in Section 11.1.2 can be met but each analyte spectrum will contain extraneous ions contributed by the coeluting compound.

11.1.4 Structural isomers that produce very similar mass spectra can be explicitly identified only if they have sufficiently different GC retention times. Acceptable resolution is achieved if the height of the valley between two isomer peaks is less than 25% of the sum of the two peak heights. Otherwise, structural isomers are identified as isomeric pairs.

12. CALCULATIONS

12.1 When an analyte has been identified, the quantitation of that analyte should be based on the integrated abundance from the EICP of the primary characteristic m/z given in Table 6. If the sample produces an interference for the primary m/z, use a secondary characteristic m/z to quantitate. Instrument calibration for secondary ions is performed, as necessary, using the data and procedures described in Sect. 8.2.

12.2 Calculate the concentration in the sample using the calibration curve or average response factor (RF) determined in Sect. 8.2.2 and Equation 3:

$$\text{Concentration (}\mu\text{g/L)} = \frac{(A_s)(C_{is})}{(A_{is})(RF)} \quad \text{Equation 3.}$$

where:

- A_s = Area of the characteristic m/z for the analyte to be measured;
- A_{is} = Area of the characteristic m/z for the internal standard;
- C_{is} = Concentration of the internal standard, in $\mu\text{g/L}$.

12.3 Report results in $\mu\text{g/L}$. All QC data obtained should be reported with the sample results.

13. ACCURACY AND PRECISION

13.1 This method has been tested in a single laboratory using spiked reagent water. Using a wide-bore capillary column, water was spiked at concentrations between 0.5 and 10 $\mu\text{g/L}$ (8). Single laboratory accuracy and precision data are presented for the method analytes in Table 4. Calculated MDLs are presented in Table 1.

13.2 The method was tested using reagent water spike at 0.1 to 0.5 $\mu\text{g/L}$ and analyzed on a cryofocused narrow-bore column. The accuracy and precision data for these compounds are presented in Table 5 (9). MDL values were also calculated from these data and are presented in Table 2.

14. REFERENCES

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9. Madding, C., Memorandum to H. Brass, June 1986.

Table / . CHROMATOGRAPHIC RETENTION TIMES AND METHOD DETECTION
LIMITS (MDL) FOR VOLATILE ORGANIC COMPOUNDS ON
NARROW BORE CAPILLARY COLUMN

ANALYTE	RETENTION TIME (mins) Column 3	MDL (ug/L)
Dichlorodifluoromethane	0.88	0.11
Chloromethane	0.97	0.05
Vinyl chloride	1.04	0.04
Bromomethane	1.29	0.06
Chloroethane	1.45	0.02
Trichlorofluoromethane	1.77	0.07
1,1-Dichloroethene	2.33	0.05
Methylene Chloride	2.66	0.09
trans-1,2-Dichloroethene	3.54	0.03
1,1-Dichloroethane	4.03	0.03
cis-1,2-Dichloroethene	5.07	0.06
2,2-Dichloropropane	5.31	0.08
Chloroform	5.55	0.04
Bromochloromethane	5.63	0.09
1,1,1-Trichloroethane	6.76	0.04
1,2-Dichloroethane	7.00	0.02
1,1-Dichloropropene	7.16	0.12
Carbon Tetrachloride	7.41	0.02
Benzene	7.41	0.03
1,2-Dichloropropane	8.94	0.02
Trichloroethene	9.02	0.02
Dibromomethane	9.09	0.10
Bromodichloromethane	9.34	0.03
Toluene	11.51	0.08
1,1,2-Trichloroethane	11.99	0.08
1,3-Dichloropropane	12.48	0.08
Dibromochloromethane	12.80	0.07
Tetrachloroethene	13.20	0.06
1,2-Dibromoethane	13.60	0.10
Chlorobenzene	14.33	0.03
1,1,1,2-Tetrachloroethane	14.73	0.07
Ethylbenzene	14.73	0.03
p-Xylene	15.30	0.06
m-Xylene	15.30	0.03
Bromoform	15.70	0.20
o-Xylene	15.78	0.06
Styrene	15.78	0.27
1,1,2,2-Tetrachloroethane	15.78	0.20
1,2,3-Trichloropropane	16.26	0.09
Isopropylbenzene	16.42	0.10

Table / . (Continued)

ANALYTE	RETENTION TIME (mins)	MDL (ug/L)
Bromobenzene	16.42	0.11
2-Chlorotoluene	16.74	0.08
n-Propylbenzene	16.82	0.10
4-Chlorotoluene	16.82	0.06
1,3,5-Trimethylbenzene	16.99	0.06
tert-Butylbenzene	17.31	0.33
1,2,4-Trimethylbenzene	17.31	0.09
sec-Butylbenzene	17.47	0.12
1,3-Dichlorobenzene	17.47	0.06
p-Isopropyltoluene	17.63	0.26
1,4-Dichlorobenzene	17.63	0.04
1,2-Dichlorobenzene	17.79	0.06
n-Butylbenzene	17.96	0.10
1,2-Dibromo-3-Chloropropane	18.03	0.50
1,2,4-Trichlorobenzene	18.84	0.20
Naphthalene	19.07	0.10
Hexachlorobutadiene	19.24	0.10
1,2,3-Trichlorobenzene	19.24	0.14
INTERNAL STANDARD		
Fluorobenzene	8.81	6.45

Column - 30 meter x 0.32mm ID DB-5 capillary with μ m film thickness

Table 2. BFB KEY m/z ABUNDANCE CRITERIA

Mass	m/z Abundance Criteria
50	15 to 40% of mass 95
75	30 to 60% of mass 95
95	Base Peak, 100% Relative Abundance
96	5 to 9% of mass 95
173	< 2% of mass 174
174	> 50% of mass 95
175	5 to 9% of mass 174
176	> 95% but < 101% of mass 174
177	5 to 9% of mass 176

Table 3. CHARACTERISTIC MASSES (m/z) FOR PURGEABLE ORGANICS COMPOUNDS

Analyte	Primary Characteristic Ion	Secondary Characteristic Ions
Benzene	78	-
Bromobenzene	156	77, 158
Bromochloromethane	128	49, 130
Bromodichloromethane	83	85, 127
Bromoform	173	175, 254
Bromomethane	94	96
n-Butylbenzene	91	92, 134
sec-Butylbenzene	106	134
tert-Butylbenzene	119	91, 134
Carbon tetrachloride	117	119
Chlorobenzene	112	77, 114
Chloroethane	64	66
Chloroform	83	85
Chloromethane	50	52
2-Chlorotoluene	91	126
4-Chlorotoluene	91	126
1,2-Dibromo-3-Chloropropane	75	155, 157
Dibromochloromethane	129	127
1,2-Dibromoethane	107	109, 188
Dibromomethane	93	95, 174
1,2-Dichlorobenzene	146	111, 148
1,3-Dichlorobenzene	146	111, 148
1,4-Dichlorobenzene	146	111, 148
Dichlorodifluoromethane	88	87
1,1-Dichloroethane	63	65, 83
1,2-Dichloroethane	62	98
1,1-Dichloroethane	96	61, 63
cis-1,2-Dichloroethane	96	61, 98
trans-1,2-Dichloroethane	96	61, 98
1,2-Dichloropropane	63	112
1,3-Dichloropropane	76	78
2,2-Dichloropropane	77	97
1,1-Dichloropropane	75	110, 77
Ethylbenzene	91	106
Hexachlorobutadiene	223	223, 227
Isopropylbenzene	106	120
p-Isopropyltoluene	119	134, 91
Methylene chloride	84	86, 49
Naphthalene	128	-
n-Propylbenzene	91	120
Styrene	104	78
1,1,1,2-Tetrachloroethane	131	133, 119

Table 3. (Continued)

Analyte	Primary Ion	Secondary Ions
1,1,2,2-Tetrachloroethane	83	131, 85
Tetrachloroethene	166	166, 129
Toluene	92	91
1,2,3-Trichlorobenzene	180	182, 145
1,2,4-Trichlorobenzene	180	182, 145
1,1,1-Trichloroethane	97	99, 61
1,1,2-Trichloroethane	83	97, 85
Trichloroethene	95	130, 132
Trichlorofluoromethane	101	103
1,2,3-Trichloropropane	75	77
1,2,4-Trimethylbenzene	106	120
1,3,5-Trimethylbenzene	106	120
Vinyl Chloride	62	64
o-Xylene	106	91
m-Xylene	106	91
p-Xylene	106	91
INTERNAL STANDARDS/SURROGATES		
Fluorobenzene	96	70
1,2-Dichlorobenzene-d ₄	150	115, 152
p-Bromofluorobenzene	96	174, 176

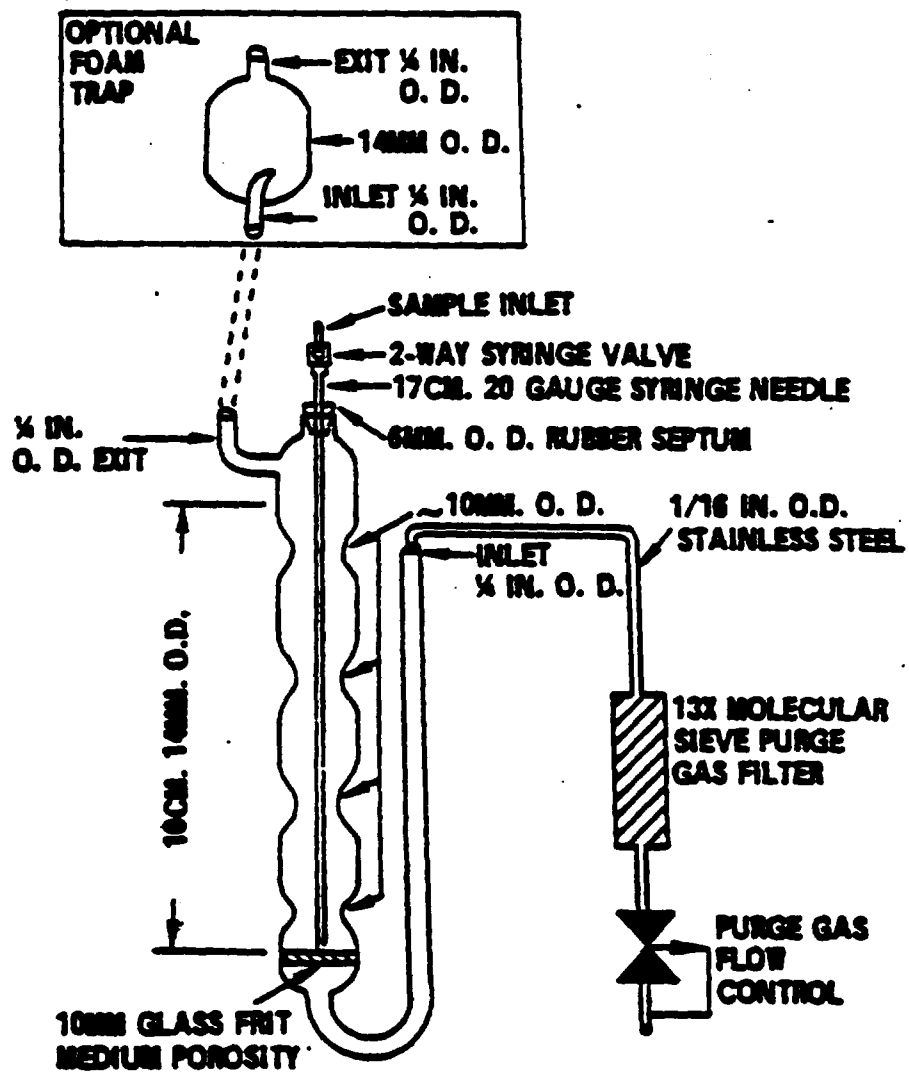


Figure 1. Purging device

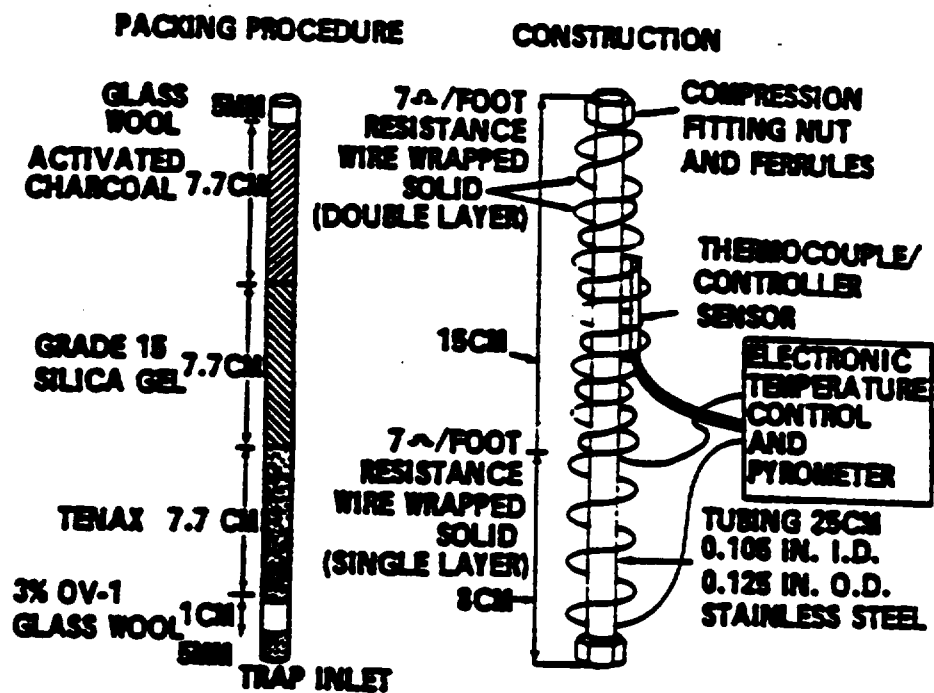


Figure 2. Trap packings and construction to include desorb capability

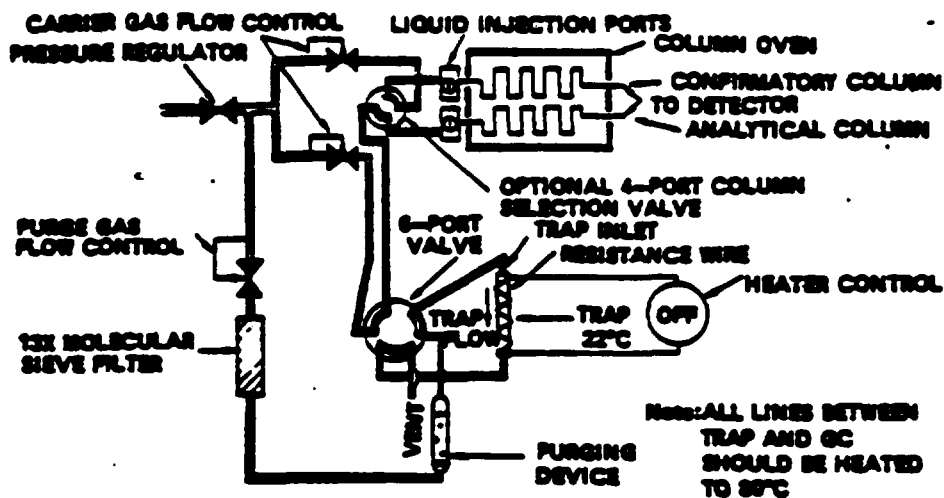


Figure 3. Purge and trap system - purge mode.

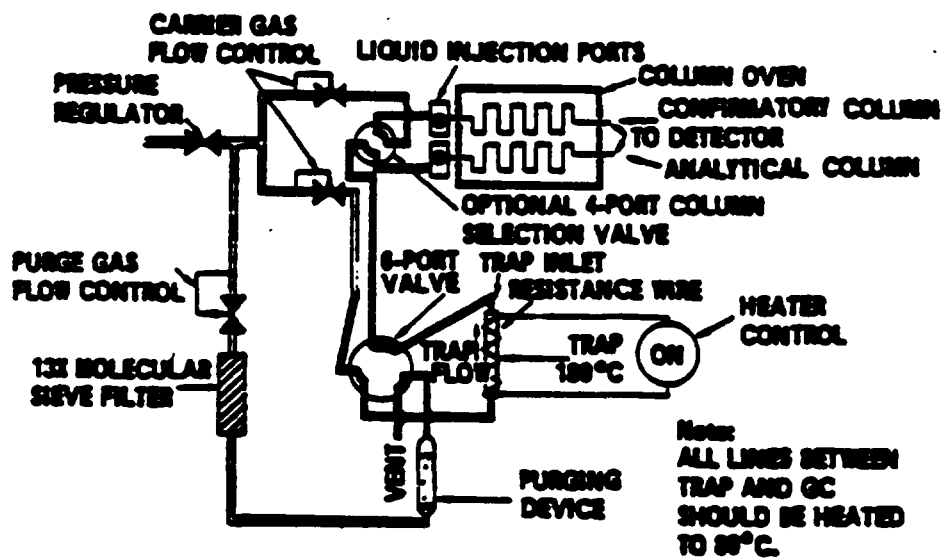


Figure 4. Schematic of purge and trap device - desorb mode

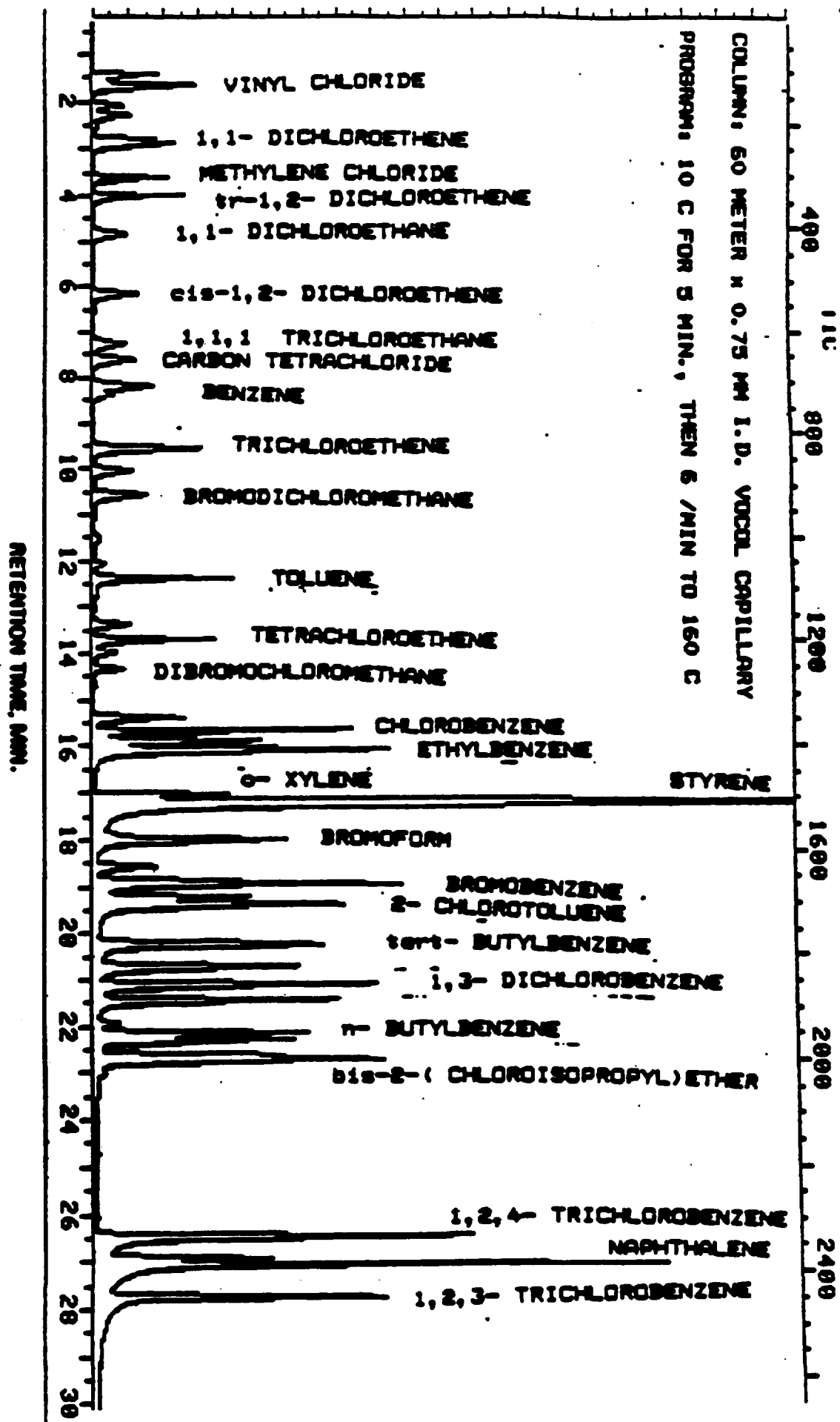


Figure 5. Gas chromatogram of volatile organics.

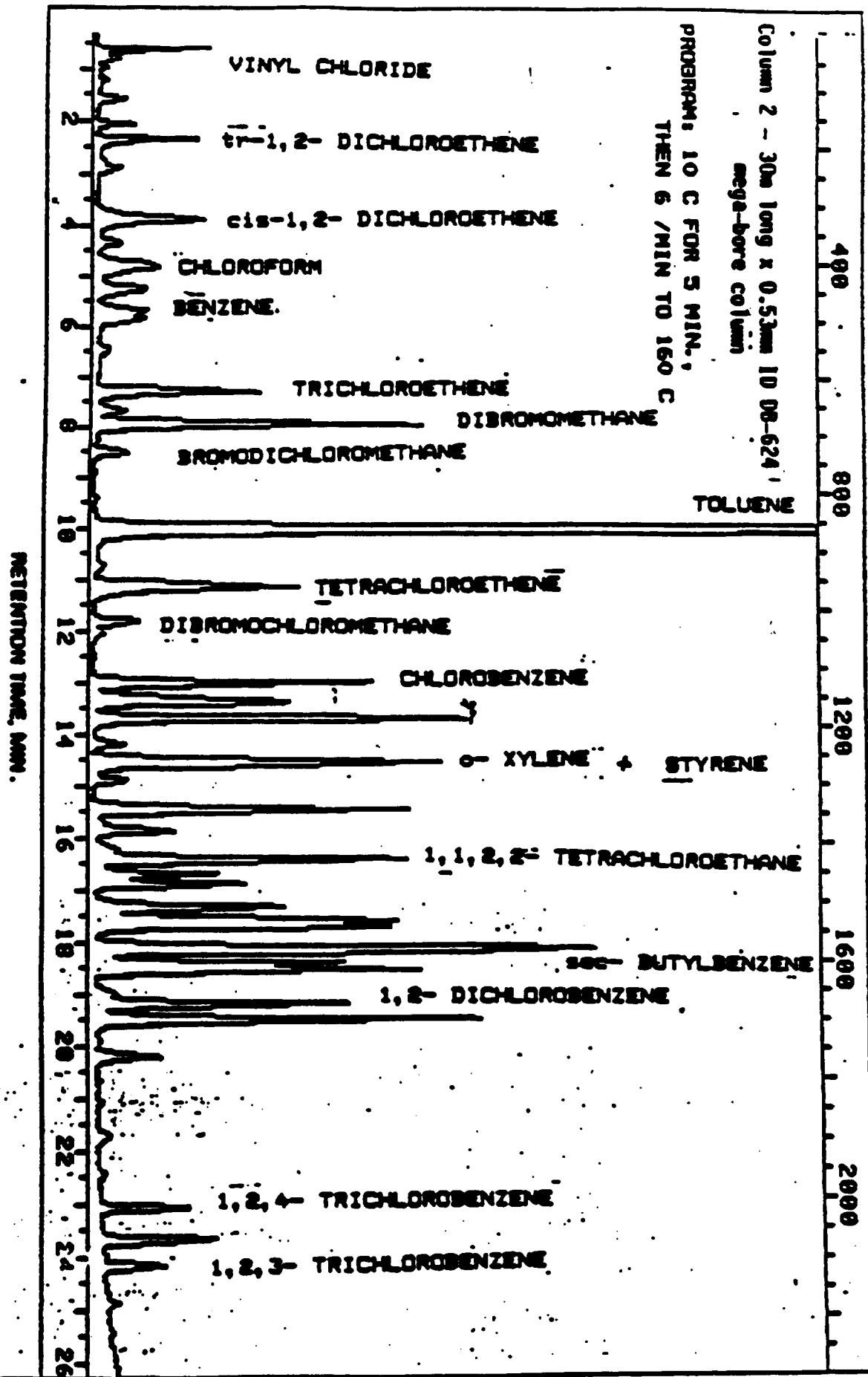


Figure 6. Gas chromatogram of volatile organics.

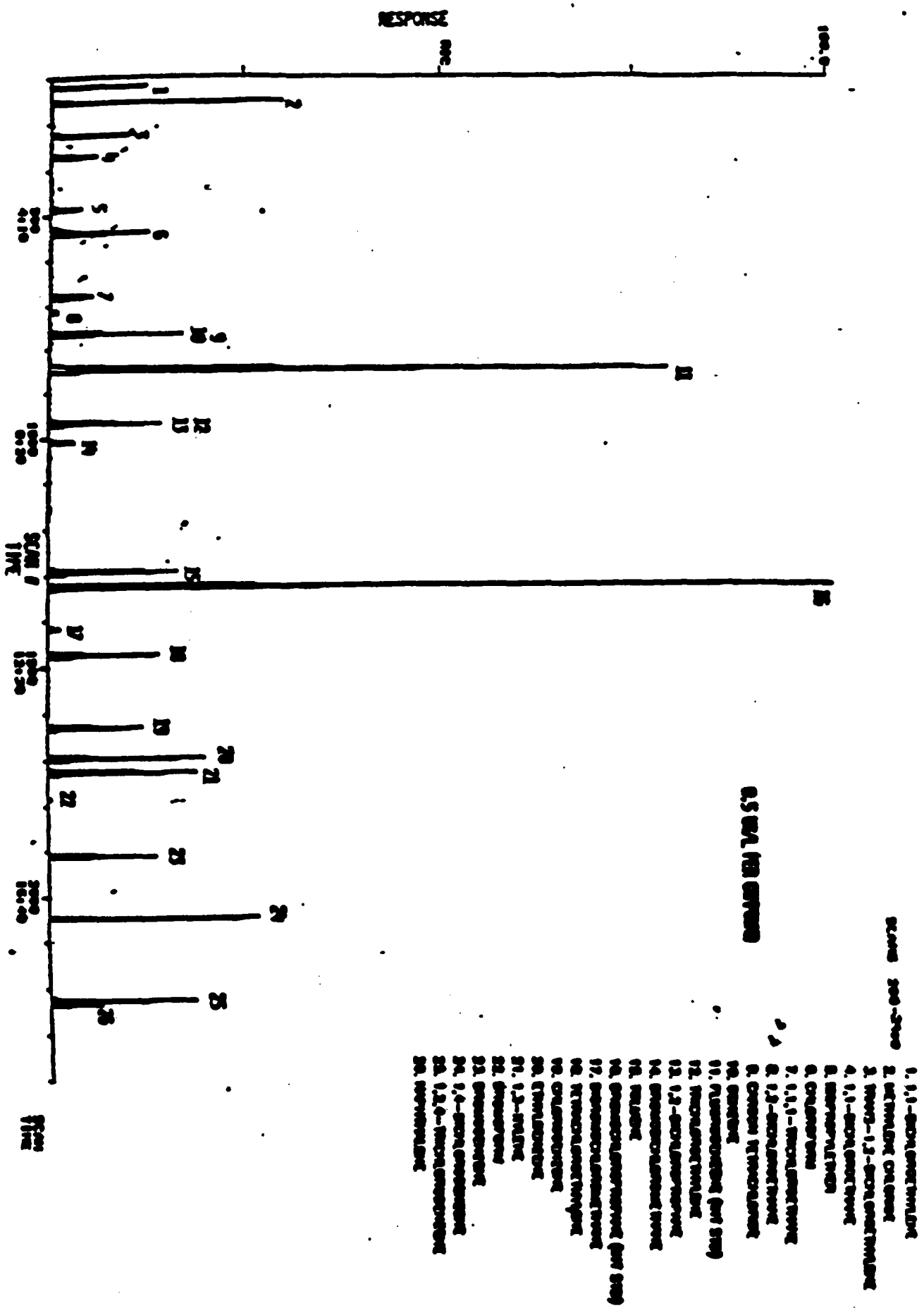


Figure 7. CHROMATOGRAM OF TEST MIXTURE

Appendix B
Attachment B-5
SPECIAL ANALYTICAL SERVICES (SAS)
FOR GEOTECHNICAL PARAMETERS

PARTICLE SIZE ANALYSIS
ATTERBERG LIMITS
LABORATORY COMPACTION (MOISTURE-DENSITY RELATIONS)
LABORATORY HYDRAULIC CONDUCTIVITY
WATER CONTENT
SPECIFIC GRAVITY

U.S. Environmental Protection Agency
HWI Sample Management Office
P.O. Box 818, Alexandria, Virginia 22313
PHONE: (703) 557-2490 or FTS-557-2490

SAS Number

SPECIAL ANALYTICAL SERVICES
Regional Request

☐

Regional Transmittal

☐

Telephone Request

A. EPA Region and Site Name: Region V Northside Landfill-ECC Site, Indiana

B. Regional Representative: Dennis Wesolowski

C. Telephone Number: (312) 886-1971

D. Date of Request: _____

Please provide below a description of your request for Special Analytical Services under the Uncontrolled Hazardous Waste Dumpsite Program. In order to most efficiently obtain laboratory capability for your request, please address the following considerations, if applicable. Incomplete or erroneous information may result in delay in the processing of your request. Please continue response on additional sheets, or attach supplementary information as needed.

1. General description of analytical service requested: _____

Soil samples analyzed for grain size, Atterberg Limits (including water content),

hydraulic conductivity, laboratory compaction, specific gravity, and water content.

2. Definition and number of work units involved (specify whether whole samples or fractions; whether organics or inorganics; whether aqueous or soil and sediments; and whether low, medium, or high concentration): Analyze 60 soil samples for particle-size distribution, 44 soil samples for Atterberg Limits and water content, 11 soil samples for hydraulic conductivity, 17 samples for laboratory compaction (moisture-density relations), 6 samples for specific gravity, and 22 samples for water content.

3. Purpose of analysis (specify whether Superfund (Remedial or Enforcement), RCRA, NPDES, etc.):

Enforcement, Predesign Investigation

4. Estimated date(s) of collection: _____

5. Estimated date(s) and method of shipment: Shipped as a group after all are collected.

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Particle Size Analysis of Soils, ASTM Method D-422 and D-421.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use only the method specified above. Obtain approval of CPMS, CRL prior to use of any other method. Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Submit all raw data including container tare weights with test results. See laboratory procedure.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> ($\pm\%$ or Conc.)
See Laboratory Procedure	Not Applicable	

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* ($\pm\%$ or Conc.)</u>
Lab Duplicate	1 per 15	5% passing any
		given sieve size

III. *Action Required If Limits are Exceeded:

Reanalyze, Contact David Lane at CH2M HILL if limits are exceeded.

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Liquid Limit Plastic Limit, and Plasticity Index, Plastic Limit, and Natural

Water Content of Soils ASTM D-4318 and D-2216.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Multipoint Liquid Limit using Procedure A-Wet Preparation. Use only the method specified above. Obtain approval of CPMS, CRL, prior to use of any other method.

Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Report all raw data with test results. See laboratory procedure for reporting requirements.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

-3-

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (\pm % or Conc.)
See Laboratory Procedures		

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits*</u> (\pm % or Conc.)
Lab Duplicate	1 per 10	+ 3% water content

III. *Action Required If Limits are Exceeded:

Reanalyze, contact David Lane at CH2M HILL if limits are exceeded.

PERMEABILITY TESTS WITH BACK PRESSURE

-2-

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Permeability Tests with Back Pressure, "Laboratory Soils Testing," Engineer Manual EM 1110-2-1906, Department of the Army, Office of the Chief of Engineer, Washington, D.C. 20314. Permeability tests will be conducted on remolded Soil Samples based on the laboratory compaction results. Three separate soil batches will be obtained and tested. All specimens will be uniformly compacted in 5 or 6 layers using a small diameter (approx. 0.3 to 0.5 inches) spring loaded or pneumatic tamping rod. All samples will be compacted to 95 percent (+ 1%) of maximum dry density (ASTM D-1557). One sample from each batch will be compacted at optimum water content, 2 percent dry of optimum and 2 percent wet of optimum. A single sample from one batch will be compacted at a molding water content that is 4 percent wet of optimum.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use only the method specified above. Obtain approval of CPMS, CRL, prior to use of any other method. Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Supply all raw data and calculations along with all test results.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (±% or Conc.)
Permeability	1×10^{-8} cm/sec	Duplicates within
		1 order-of-magnitude

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (±% or Conc.)</u>
Duplicate	1 per 10	1 order-of-magnitude

III. *Action Required If Limits are Exceeded:

Reanalyze, Contact David Lane at CH2M HILL if limits are exceeded.

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

Laboratory Compaction of Soil, ASTM Method D-1557, Method A or C.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use only method specified above. Obtain approval of CPMS, CRL prior to use of any other method. Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Submit all raw data and calculations including container tare weights with test results.

Report results as specified in the laboratory procedure.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

-3-

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> ($\pm\%$ or Conc.)
See Laboratory Procedure		

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits*</u> ($\pm\%$ or Conc.)
Lab Duplicate	1 per 10	See laboratory procedure
	moisture-density	
	relationships	

III. *Action Required if Limits are Exceeded:

Reanalyzed, contact David Lane at CH2M HILL if limits are exceeded.

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of samples.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ASTM Method D-854

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Submit all raw data with test results. See laboratory procedure.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

-3-

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (\pm or Conc.)
See Laboratory Procedure		

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (\pm or Conc.)</u>
Lab Duplicate	1 per 5	See laboratory procedure

III. *Action Required if Limits are Exceeded:

Contact David Lane/CH2M HILL

6. Approximate number of days results required after lab receipt of samples: _____

Laboratory should report results within 30 days of receipt of sample.

7. Analytical protocol required (attach copy if other than a protocol currently used in this program):

ASTM Method D 2216-80: Standard Method for Laboratory Determination of Water

(moisture) content of soil, rock, and soil-aggregate mixtures.

8. Special technical instructions (if outside protocol requirements, specify compound names, CAS numbers, detection limits, etc.):

Use only the method specified above. Obtain approval of CPMS, CRL prior to use of any other method. Rewrite SAS request to reflect new methodology.

9. Analytical results required (if known, specify format for data sheets, QA/QC reports, Chain-of-Custody documentation, etc.). If not completed, format of results will be left to program discretion.

Report all raw data and parameter values used in making calculations of moisture content.

10. Other (use additional sheets or attach supplementary information, as needed):

11. Name of sampling/shipping contact: David Lane

Phone: 414/272-2426

Please return this request to the Sample Management Office as soon as possible to expedite processing of your request for special analytical services. Should you have any questions or need any assistance, please call the Sample Management Office.

MOISTURE CONTENT

-3-

I. DATA REQUIREMENTS

<u>Parameter</u>	<u>Detection Limit</u>	<u>Precision Desired</u> (\pm % or Conc.)
Moisture Content	1%	Duplicates within 10%

II. QUALITY CONTROL REQUIREMENTS

<u>Audits Required</u>	<u>Frequency of Audits</u>	<u>Limits* (\pm% or Conc.)</u>
Duplicate	2 for sets \leq 10 1 per 10 for sets $>$ 10	10%

III. *Action Required If Limits are Exceeded:

Reanalyze. Contact Chuck Elly at Region 5, CRL. Phone Number (312) 353-9057.



Designation: D 422 - 63 (Reapproved 1972)¹

Standard Method for PARTICLE-SIZE ANALYSIS OF SOILS¹

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

¹ NOTE—Section 2 was added editorially and subsequent sections renumbered in July 1984.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425- μm), or No. 200 (75- μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20- μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm .

2. Applicable Documents

2.1 ASTM Standards:

D 421 Method for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants²

E 11 Specification for Wire-Cloth Sieves for Testing Purposes³

E 100 Specification for ASTM Hydrometers⁴

3. Apparatus

3.1 **Balances**—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing

the material retained on a No. 10 sieve.

3.2 **Stirring Apparatus**—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than $\frac{3}{4}$ in. (19.0 mm) nor more than $1\frac{1}{2}$ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup⁵ (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft³/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

Current edition approved Nov. 21, 1963. Originally published 1933. Replaces D 422 - 62.

² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Annual Book of ASTM Standards, Vol 14.01.

⁵ Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Order Adjunct No. 12-404220-00.

results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

3-in. (75-mm)	No. 10 (2.00-mm)
2-in. (50-mm)	No. 20 (850-μm)
1½-in. (37.5-mm)	No. 40 (425-μm)
1-in. (25.0-mm)	No. 60 (250-μm)
¾-in. (19.0-mm)	No. 140 (106-μm)
½-in. (9.5-mm)	No. 200 (75-μm)
No. 4 (4.75-mm)	

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)	No. 16 (1.18-mm)
1½-in. (37.5-mm)	No. 30 (600-μm)
¾-in. (19.0-mm)	No. 50 (300-μm)
½-in. (9.5-mm)	No. 100 (150-μm)
No. 4 (4.75-mm)	No. 200 (75-μm)
No. 8 (2.36-mm)	

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant

temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Method D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Method D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
¾ (9.5)	500
¾ (19.0)	1000

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Method D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ½-in. (12.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hy-

drometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/l). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75- μ m) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the $\frac{1}{2}$ -in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the $\frac{1}{2}$ -in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correc-

tion factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

a = correction factor to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1).

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension.

R = hydrometer reading with composite correction applied (Section 7).

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g.

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1 .

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. Accord-

ing to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

where:

- D = diameter of particle, mm,
- n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),
- L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)),
- T = interval of time from beginning of sedimentation to the taking of the reading, min.
- G = specific gravity of soil particles, and
- G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

- K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A - and B -scales, the square root being indicated on the D -scale. Without ascertaining the value of the square root it may be multiplied by K , using either the C - or CI -scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the

fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

17. Graph

17.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

- | | | |
|--|-------|---|
| (1) Gravel, passing 3-in. and retained on No. 4 sieve | | % |
| (2) Sand, passing No. 4 sieve and retained on No. 200 sieve | | % |
| (a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve | | % |
| (b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve | | % |
| (c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve | | % |
| (3) Silt size, 0.074 to 0.005 mm | | % |

- | | | |
|--------------------------------------|-------|---|
| (4) Clay size, smaller than 0.005 mm | | % |
| Colloids, smaller than 0.001 mm | | % |

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS	
Sieve Size	Percentage Passing
3-in.
2-in.
1½-in.
1-in.
¾-in.
½-in.
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-µm)
No. 200 (75-µm)
HYDROMETER ANALYSIS	
0.074 mm
0.005 mm
0.001 mm

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

TABLE 1 Values of Correction Factor, c , for Different Specific Gravities of Soil Particles^a

Specific Gravity	Correction Factor ^a
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

^a For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes^a

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5

TABLE 2 Continued

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

^a Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2} [L_2 - (V_0/A)]$$

where:

- L = effective depth, cm.
- L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm.
- L_2 = overall length of the hydrometer bulb, cm.
- V_0 = volume of hydrometer bulb, cm³, and
- A = cross-sectional area of sedimentation cylinder, cm²

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

$$L_1 = 14.0 \text{ cm}$$

$$V_0 = 67.0 \text{ cm}^3$$

$$A = 27.8 \text{ cm}^2$$

For hydrometer 151H:

$$L_1 = 10.5 \text{ cm for a reading of 1.000}$$

$$= 2.3 \text{ cm for a reading of 1.031}$$

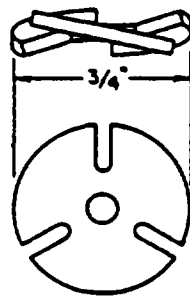
For hydrometer 152H:

$$L_1 = 10.5 \text{ cm for a reading of 0 g/litre}$$

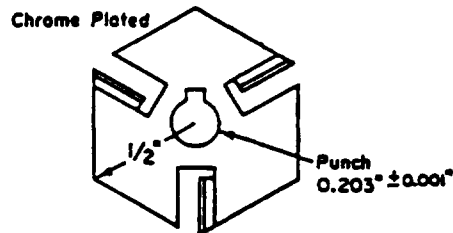
$$= 2.3 \text{ cm for a reading of 50 g/litre}$$

TABLE 3 Values of *K* for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149



(a)

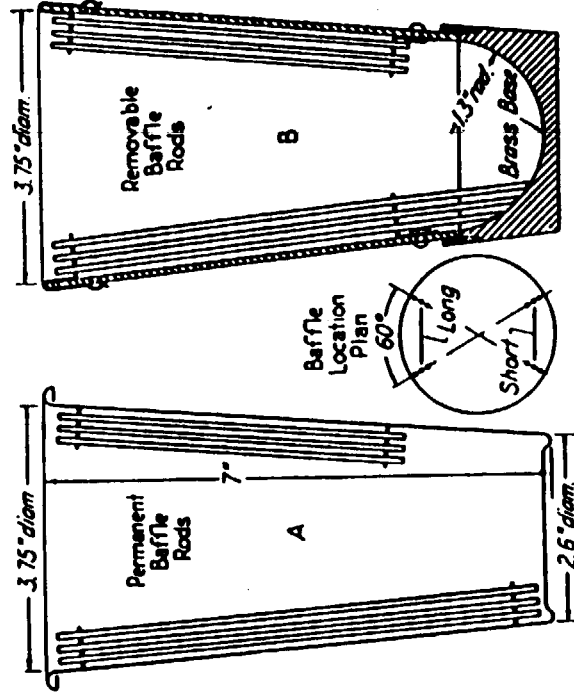


(b)

Metric Equivalents					
in.	0.001	0.049	0.203	1/2	3/4
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

D 422



Metric Equivalents	
in.	1.3
mm	33
	2.6
	66
	3.75
	95.2

FIG. 2 Dispersion Cups of Apparatus

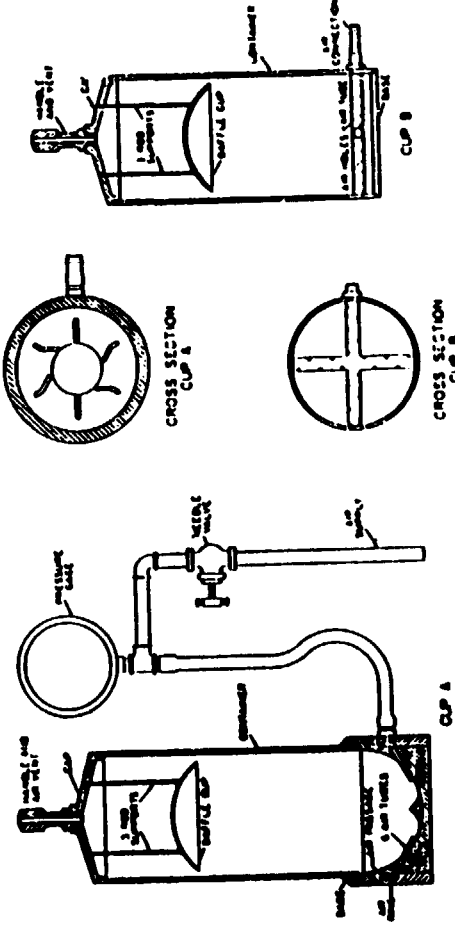
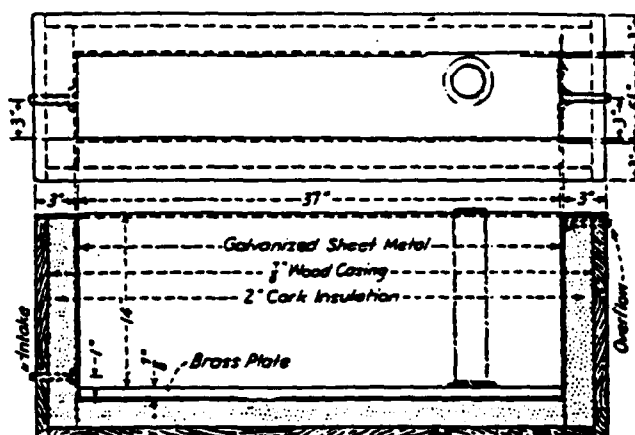


FIG. 3 Air-Jet Dispersion Cups of Apparatus B



Metric Equivalents						
in.	1/2	1	3	6 1/4	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

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Standard Test Method for LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS¹

This standard is issued under the fixed designation D 4318; the number immediately following the designation indicates the year of adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. An asterisk (*) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

Scope

1 This test method covers the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3.

1.1 Two procedures for preparing test specimens and two procedures for performing the liquid limit are provided as follows:

- A Multipoint test using a wet preparation procedure, described in Sections 10.1, 11, and 12.
- B Multipoint test using a dry preparation procedure, described in Sections 10.2, 11, and 12.
- C One-point test using a wet preparation procedure, described in Sections 13, 14, and 15.
- D One-point test using a dry preparation procedure, described in Sections 13, 14, and 15.

The procedure to be used shall be specified by the requesting authority. If no procedure is specified, Procedure A shall be used.

NOTE 1—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

1.1.2 The plastic limit test procedure is described in Sections 16, 17, and 18. The plastic limit test is performed on material prepared for the liquid limit test. In effect, there are two procedures for preparing test specimens for the plastic limit test.

1.1.3 The procedure for calculating the plasticity index is given in Section 19.

1.2 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits in recognition of their formation by Swedish soil scientist, A. Atterberg. These limits distinguish the boundaries of the several consistency states of plastic soils.

1.3 As used in this test method, soil is any natural aggregation of mineral or organic materials, mixtures of such materials, or artificial mixtures of aggregates and natural mineral and organic particles.

1.4 The multipoint liquid limit procedure is somewhat more time consuming than the one-point procedure when both are performed by experienced operators. However, the one-point procedure requires the operator to judge when the test specimen is approximately at its liquid limit. In cases where this is not done reliably, the multipoint procedure is as fast as the one-point procedure and provides additional precision due to the information obtained from additional trials. It is particularly recommended that the multipoint procedure be used by inexperienced operators.

1.5 The correlations on which the calculations of the one-point procedure are based may not be valid for certain soils, such as organic soils or

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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soils from a marine environment. The liquid limit of these soils should therefore be determined by the multipoint procedure (Procedure A).

1.6 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.7 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D 2216). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given consideration if meaningful results are to be obtained.

1.8 Since the tests described herein are performed only on that portion of a soil which passes the 425- μ m (No. 40) sieve, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate the properties of a soil.

1.9 The values stated in acceptable metric units are to be regarded as the standard. The values given in parentheses are for information only.

1.10 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 ASTM Standards:

- C 702 Methods for Reducing Field Samples of Aggregate to Testing Size²
- D 75 Practice for Sampling Aggregates³
- D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes⁴

D 653 Terms and Symbols Relating to Soil and Rock⁴

D 1241 Specification for Materials for Aggregate Subbase, Base, and Surface Courses⁴

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Soil-Aggregate Mixtures⁴

D 2240 Test Method for Rubber Property—Durometer Hardness³

D 2487 Test Method for Classification of Soils for Engineering Purposes⁴

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)⁴

D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes⁴

E 11 Specification for Wire-Cloth Sieves for Testing Purposes⁶

E 319 Methods of Testing Single-Arm Pendulums⁶

E 898 Method of Testing Top-Loading Direct-Reading Laboratory Scales and Balances⁶

3. Definitions

3.1 *Atterberg limits*—originally, seven “limits of consistency” of fine-grained soils were defined by Albert Atterberg. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.2 *consistency*—the relative ease with which a soil can be deformed.

3.3 *liquid limit (LL)*—the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. The water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (½ in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of 2 shocks per second.

² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vols 04.02, 04.03, 04.08.

⁴ Annual Book of ASTM Standards, Vol 04.08.

⁵ Annual Book of ASTM Standards, Vol 09.01.

⁶ Annual Book of ASTM Standards, Vol 14.02.

NOTE 2—The undrained shear strength of soil at the liquid limit is considered to be 2 ± 0.2 kPa (0.28 psi).

3.4 *plastic limit (PL)*—the water content, in percent, of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2 mm (¼ in.) in diameter threads without crumbling.

3.5 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.6 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.7 *liquidity index*—the ratio, expressed as a percentage, of (1) the natural water content of a soil minus its plastic limit, to (2) its plasticity index.

3.8 *activity number (A)*—the ratio of (1) the plasticity index of a soil to (2) the percent by weight of particles having an equivalent diameter smaller than 0.002 mm.

4. Summary of Method

4.1 The sample is processed to remove any material retained on a 425- μ m (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the sample is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Procedures A and B, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Procedures C and D, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2 mm (¼ in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and is no longer able to be pressed together and rerolled. The water content of the soil at this stage is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 This test method is used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Test Method D 2487 and Practice D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together with other soil properties to correlate with engineering behavior such as compressibility, permeability, compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil can be used with the natural water content of the soil to express its relative consistency or liquidity index and can be used with the percentage finer than 2- μ m size to determine its activity number.

5.3 The one-point liquid limit procedure is frequently used for routine classification purposes. When greater precision is required, as when used for the acceptance of a material or for correlation with other test data, the multipoint procedure should be used.

5.4 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.5 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil.

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto a hard rubber base. A drawing showing the essential features of the device and the critical dimensions is given in Fig. 1. The design of the device may vary provided that the essential functions are

preserved. The device may be operated either by a hand crank or by an electric motor.

6.1.1 *Base*—The base shall be hard rubber having a D Durometer hardness of 80 to 90, and a resilience such that an 8-mm ($\frac{5}{16}$ -in.) diameter polished steel ball, when dropped from a height of 25 cm (9.84 in.) will have an average rebound of at least 80 % but no more than 90 %. The tests shall be conducted on the finished base with feet attached.

6.1.2 *Feet*—The base shall be supported by rubber feet designed to provide isolation of the base from the work surface and having an A Durometer hardness no greater than 60 as measured on the finished feet attached to the base.

6.1.3 *Cup*—The cup shall be brass and have a weight, including cup hanger, of 185 to 215 g.

6.1.4 *Cam*—The cam shall raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation. The preferred cam motion is a uniformly accelerated lift curve. The design of the cam and follower combination shall be such that there is no upward or downward velocity of the cup when the cam follower leaves the cam.

NOTE 3—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 *Carriage*—The cup carriage shall be constructed in a way that allows convenient but secure adjustment of the height of drop of the cup to 10 mm (0.394 in.). The cup hanger shall be attached to the carriage by means of a pin which allows removal of the cup and cup hanger for cleaning and inspection.

6.1.6 *Optional Motor Drive*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ± 0.1 revolutions per second, and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height of drop adjustments. The results obtained using a motor-driven device

must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A grooving tool having dimensions shown in Fig. 2. The tool may be made of plastic or noncorroding metal. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gage for adjusting height of drop of the liquid limit device.

6.3 *Gage*—A metal gage block for adjusting the height of drop of the cup, having the dimensions shown in Fig. 3. The design of the tool may vary provided the gage will rest securely on the base without being susceptible to rocking on the edge which contacts the cup during adjustment is straight, at least 10 mm ($\frac{3}{8}$ in.) wide, without bevel or radius.

6.4 *Containers*—Small corrosion-resistant containers with snug-fitting lids for water control specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance*—A balance readable to at least 0.01 g and having an accuracy of 0.03 g within three standard deviations within the range of use. Within any 15-g range, a difference between readings shall be accurate within 0.01 g (Notes 4 and 5).

NOTE 4—See Methods E 898 and E 319 for explanation of terms relating to balance performance.

NOTE 5—For frequent use, a top-loading type balance with automatic load indication, readable to 0.01 g, and having an index of precision (standard deviation) of 0.003 or better is most suitable for this method. However, nonautomatic indicating equal-arm analytical balances and some small equal arm top pan balances having readabilities and sensitivities of 0.002 g or better provide the required accuracy when used with a weight set of ASTM Class 4 (National Bureau of Standards Class P) or better. Ordinary commercial and classroom type balances such as beam balances are not suitable for this method.

6.6 *Storage Container*—A container in which to store the prepared soil specimen that will not contaminate the specimen in any way, and which prevents moisture loss. A porcelain, glass, or plastic dish about 11.4 cm (4½ in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Ground Glass Plate*—A ground glass plate at least 30 cm (12 in.) square by 1 cm ($\frac{3}{8}$ in.) thick for mixing soil and rolling plastic limit threads.

6.8 *Spatula*—A spatula or pill knife having a

blade about 2 cm ($\frac{3}{4}$ in.) wide by about 10 cm (4 in.) long. In addition, a spatula having a blade about 2.5 cm (1 in.) wide and 15 cm (6 in.) long has been found useful for initial mixing of samples.

6.9 *Sieve*—A 20.3 cm (8 in.) diameter, 425- μ m (No. 40) sieve conforming to the requirements of Specification E 11 and having a rim at least 5 cm (2 in.) above the mesh. A 2-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle*, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

6.11 *Drying Oven*—A thermostatically controlled oven, preferably of the forced-draft type, capable of continuously maintaining a temperature of $110 \pm 5^\circ\text{C}$ throughout the drying chamber. The oven shall be equipped with a thermometer of suitable range and accuracy for monitoring oven temperature.

6.12 *Washing Pan*—A round, flat-bottomed pan at least 7.6 cm (3 in.) deep, slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

6.13 *Rod (optional)*—A metal or plastic rod or tube 3.2 mm ($\frac{1}{8}$ in.) in diameter and about 10 cm (4 in.) long for judging the size of plastic limit threads.

7. Materials

7.1 A supply of distilled or demineralized water.

8. Sampling

8.1 Samples may be taken from any location that satisfies testing needs. However, Methods C 702, and Practice D 75, and Recommended Practice D 420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples which will be prepared using the wet preparation procedure, 10.1, must be kept at their natural water content prior to preparation.

8.2 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.3 Where data from this test method are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425- μ m (No. 40) sieve. Free flowing samples may be reduced by the methods of quartering or splitting. Cohesive samples shall be mixed thoroughly in a pan with a spatula, or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

9.1 Inspection of Wear:

9.1.1 *Liquid Limit Device*—Determine that the liquid limit device is clean and in good working order. The following specific points should be checked:

9.1.1.1 *Wear of Base*—The spot on the base where the cup makes contact should be worn no greater than 10 mm ($\frac{3}{8}$ in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing does not make the base thinner than specified in 6.1 and the other dimensional relationships are maintained.

9.1.1.2 *Wear of Cup*—The cup must be replaced when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the edge of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3-mm ($\frac{1}{8}$ -in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 *Wear of Cam*—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.2 *Grooving Tools*—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made and the types of soils being tested. Sandy soils cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils. Any tool with a tip width greater than 2.1 mm must not be used. The depth

of the tip of the grooving tool must be 7.9 to 8.1 mm.

NOTE 6—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimetre scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth measuring feature of vernier calipers.

9.2 Adjustment of Height of Drop—Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm. See Fig. 4 for proper location of the gage relative to the cup during adjustment.

NOTE 7—A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gage under the cup from the front, and observe whether the gage contacts the cup or the tape. See Fig. 4. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gage in position against the tape and cup. If a ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height of drop. If the cup rocks on the gage during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

MULTIPOINT LIQUID LIMIT—PROCEDURES A AND B

10. Preparation of Test Specimens

10.1 Wet Preparation—Except where the dry method of specimen preparation is specified (10.2), prepare specimens for test as described in the following sections.

10.1.1 Samples Passing the 425- μ m (No. 40) Sieve—When by visual and manual procedures it is determined that the sample has little or no material retained on a 425- μ m (No. 40) sieve, prepare a specimen of 150 to 200 g by mixing thoroughly with distilled or demineralized water on the glass plate using the spatula. If desired, soak soil in a storage dish with small amount of water to soften the soil before the start of mixing.

Adjust the water content of the soil to bring a consistency that would require 25 to 35 blows of the liquid limit device to close the grooves (Note 8). If, during mixing, a small percentage of material is encountered that would be retained on a 425- μ m (No. 40) sieve, remove these particles by hand, if possible. If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the specimen through a 425- μ m (No. 40) sieve using a piece of rubber sheeting, rubber stopper, or other convenient device provided the operation does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarser material are encountered during mixing, or if it is considered impractical to remove the coarser material by the methods just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425- μ m (No. 40) sieve, but remove by hand or by washing. Place the mixed soil in the storage dish, cover to prevent loss of moisture, and allow to stand for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 8—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 Samples Containing Material Retained on a 425- μ m (No. 40) Sieve

10.1.2.1 Select a sufficient quantity of soil at natural water content to provide 150 to 200 g of material passing the 425- μ m (No. 40) sieve. Place in a pan or dish and add sufficient water to cover the soil. Allow to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (Note 9).

NOTE 9—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results should tap water be used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for washing operations.

10.1.2.2 When the sample contains a large percentage of material retained on the 425- μ m

(No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425- μ m (No. 40) sieve in the bottom of the clean pan. Pour the soil water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, pour the soil water mixture over a 2-mm (No. 10) sieve nested atop the 425- μ m (No. 40) sieve, rinse the fine material through and remove the 2-mm (No. 10) sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm ($\frac{1}{2}$ in.) above the surface of the 425- μ m (No. 40) sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425- μ m (No. 40) sieve.

10.1.2.3 Reduce the water content of the material passing the 425- μ m (No. 40) sieve until it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (a) exposing the air currents at ordinary room temperature, (b) exposing to warm air currents from a source such as an electric hair dryer, (c) filtering in a Buckner funnel or using filter candles, (d) decanting clear water from surface of suspension, or (e) draining in a colander or plaster of paris dish lined with high retentivity, high wet-strength filter paper.⁷ If a plaster of paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to actively absorb water into its surface. Thoroughly dry dishes between uses. During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface of the mixture. For soil samples containing soluble salts, use a method of water reduction such as a or b that will not eliminate the soluble salts from the test specimen.

10.1.2.4 Thoroughly mix the material passing the 425- μ m (No. 40) sieve on the glass plate using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of

distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. The soil should be at a water content that will result in closure of the groove in 25 to 35 blows. Return the mixed soil to the mixing dish, cover to prevent loss of moisture, and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, remix the soil thoroughly.

10.2 Dry Preparation

10.2.1 Select sufficient soil to provide 150 to 200 g of material passing the 425- μ m (No. 40) sieve after processing. Dry the sample at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the sample is not allowed to completely dry. However, the soil should have a dry appearance when pulverized. Pulverize the sample in a mortar with a rubber tipped pestal or in some other way that does not cause breakdown of individual grains. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425- μ m (No. 40) sieve, but remove by hand or other suitable means, such as washing.

10.2.2 Separate the sample on a 425- μ m (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425- μ m (No. 40) sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations as many times as necessary to assure that all finer material has been disaggregated and material retained on the 425- μ m (No. 40) sieve consists only of individual sand or gravel grains.

10.2.3 Place material remaining on the 425- μ m (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir the soil water mixture and pour over the 425- μ m (No. 40) sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425- μ m (No. 40) sieve. Discard material retained on the 425- μ m (No. 40) sieve.

10.2.4 Adjust the water content as necessary by drying as described in 10.1.2.3 or by mixing on the glass plate, using the spatula while adding increments of distilled or demineralized water,

⁷S and S 595 filter paper, available in 32-cm circles, has proven satisfactory.

until the soil is at a water content that will result in closure of the groove in 25 to 35 blows.

10.2.5 Put soil in the storage dish, cover to prevent loss of moisture and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, thoroughly remix the soil (Note 8).

11. Procedure

11.1 Place a portion of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat but form the pat with as few strokes as possible. Heap the unused soil on the glass plate and cover with the inverted storage dish or a wet towel.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 5. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (½ in.). See Fig. 6.

NOTE 10—Use the end of the grooving tool, Fig. 2, or a scale to verify that the groove has closed 13 mm (½ in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving

operation and repeat 11.1 to 11.3. If the soil slides on the surface of the cup, repeat 11.1 through 11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup, if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, N , required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, place in a weighed container, and cover.

11.6 Return the soil remaining in the cup to the glass plate. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen on the glass plate adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1 through 11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W_N , of the soil specimen from each trial in accordance with Method D 2216. Make all weighings on the same balance. Initial weighings should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 min, the specimens already obtained should be weighed at the time of the interruption.

12. Calculations

12.1 Plot the relationship between the water content, W_N , and the corresponding number of drops, N , of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on the logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil. Computa-

tional methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—PROCEDURES C AND D

13. Preparation of Test Specimens

13.1 Prepare the specimen in the same manner as described in Section 10, except that at mixing, adjust the water content to a consistency requiring 20 to 30 drops of the liquid limit cup to close the groove.

14. Procedure

14.1 Proceed as described in 11.1 through 11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

14.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling operations. Repeat 11.2 through 11.5, and, if the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. Otherwise, remix the entire specimen and repeat.

NOTE 11—Excessive drying or inadequate mixing will cause the number of blows to vary.

14.3 Determine water contents of specimens as described in 11.8.

15. Calculations

15.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL = W_N \left(\frac{N}{25} \right)^{0.121} \quad \text{or}$$

$$LL = K(W_N)$$

where:

N = the number of blows causing closure of the groove at water content,

W_N = water content, and

K = a factor given in Table 1.

The liquid limit is the average of the two trial liquid limit values.

15.2 If the difference between the two trial

liquid limit values is greater than one percentage point, repeat the test.

PLASTIC LIMIT

16. Preparation of Test Specimen

16.1 Select a 20-g portion of soil from the material prepared for the liquid limit test, either after the second mixing before the test, or from the soil remaining after completion of the test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading and mixing continuously on the glass plate. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper that does not add any fiber to the soil, such as hard surface paper toweling or high wet strength filter paper.

17. Procedure

17.1 From the 20-g mass, select a portion of 1.5 to 2.0 g. Form the test specimen into an ellipsoidal mass. Roll this mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (Note 12). The thread shall be further deformed on each stroke so that its diameter is continuously reduced and its length extended until the diameter reaches 3.2 ± 0.5 mm (0.125 ± 0.020 in.), taking no more than 2 min (Note 13). The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

NOTE 12—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 13—A 3.2-mm (¼-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter, especially for inexperienced operators.

17.1.1 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and reroll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pres-

sure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (See Fig. 7). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that they are able to be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm ($\frac{1}{8}$ to $\frac{3}{8}$ in.) in length.

17.2 Gather the portions of the crumbled thread together and place in a weighed container. Immediately cover the container.

17.3 Select another 1.5 to 2.0 g portion of soil from the original 20-g specimen and repeat the operations described in 17.1 and 17.2 until the container has at least 6 g of soil.

17.4 Repeat 17.1 through 17.3 to make another container holding at least 6 g of soil. Determine the water content, in percent, of the soil contained in the containers in accordance with Method D 2216. Make all weighings on the same balance.

NOTE 14—The intent of performing two plastic limit trials is to verify the consistency of the test results. It is acceptable practice to perform only one plastic limit trial when the consistency in the test results can be confirmed by other means.

18. Calculations

18.1 Compute the average of the two contents. If the difference between the two contents is greater than two percentage points, repeat the test. The plastic limit is the average of the two water contents.

PLASTICITY INDEX

19. Calculations

19.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:

LL = the liquid limit,

PL = the plastic limit.

Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

20. Report

20.1 Report the following information:

20.1.1 Sample identifying information,

20.1.2 Any special specimen selection process used, such as removal of sand lenses from undisturbed sample,

20.1.3 Report sample as airdried if the sample was airdried before or during preparation,

20.1.4 Liquid limit, plastic limit, and plasticity index to the nearest whole number and omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP,

20.1.5 An estimate of the percentage of sample retained on the 425- μ m (No. 40) sieve, and

20.1.6 Procedure by which liquid limit was performed, if it differs from the multipoint method.

21. Precision and Bias

21.1 No interlaboratory testing program has as yet been conducted using this test method to determine multilaboratory precision.

21.2 The within laboratory precision of the results of tests performed by different operators at one laboratory on two soils using Procedure A for the liquid limit is shown in Table 2.

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	K (Factor for Liquid Limit)
20	0.974
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

TABLE 2 Within Laboratory Precision for Liquid Limit

	Average Value, \bar{x}	Standard Deviation, s
Soil A:		
PL	21.9	1.07
LL	27.9	1.07
Soil B:		
PL	20.1	1.21
LL	32.6	0.98

DIMENSIONS

LETTER	A ^Δ	B ^Δ	C ^Δ	E ^Δ	F	G	H	J ^Δ	K ^Δ	L ^Δ	M ^Δ
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0
LETTER	N	P	R	T	U ^Δ	V	W	Z			
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5			

^Δ ESSENTIAL DIMENSIONS

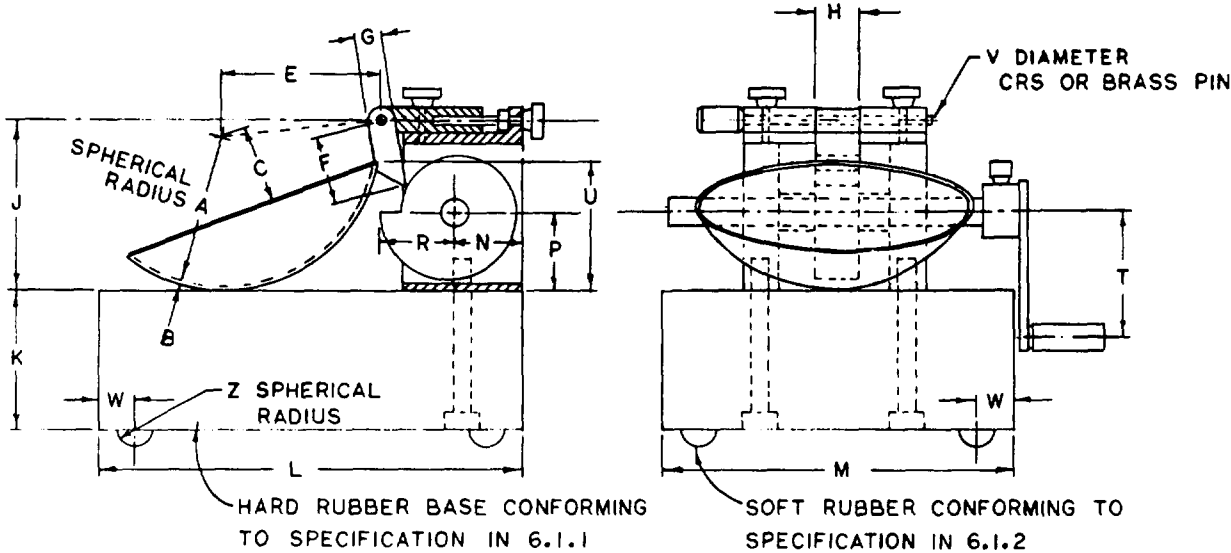


FIG. 1 Hand-Operated Liquid Limit Device

CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945 R
300	0.974 R
330	0.995 R
360	1.000 R

D 4318

D 4318

DIMENSIONS

LETTER	A ^Δ	B ^Δ	C ^Δ	D ^Δ	E ^Δ	F ^Δ
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1
LETTER	G	H	J	K ^Δ	L ^Δ	N
MM	10	13	60	10 ± 0.05	60 DEG ± 1 DEG	20

^Δ ESSENTIAL DIMENSIONS

^D BACK AT LEAST 15 MM FROM TIP

NOTE : DIMENSION A SHOULD BE 1.9-2.0 AND DIMENSION D SHOULD BE 8.0-8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

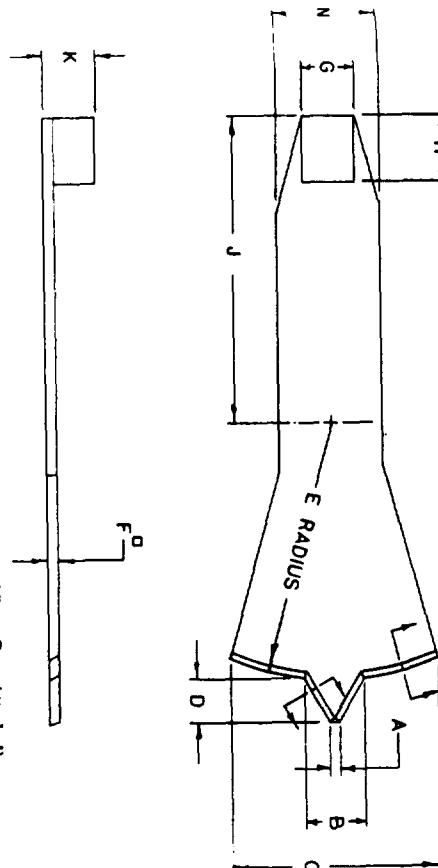
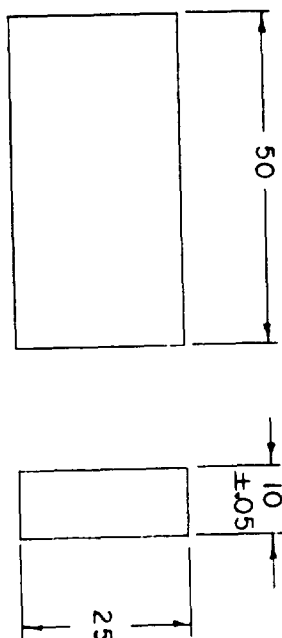


FIG. 2 Grooving Tool (Optional Height of Drop Cage Attached)



DIMENSIONS IN MILLIMETRES

FIG. 3 Height of Drop Cage

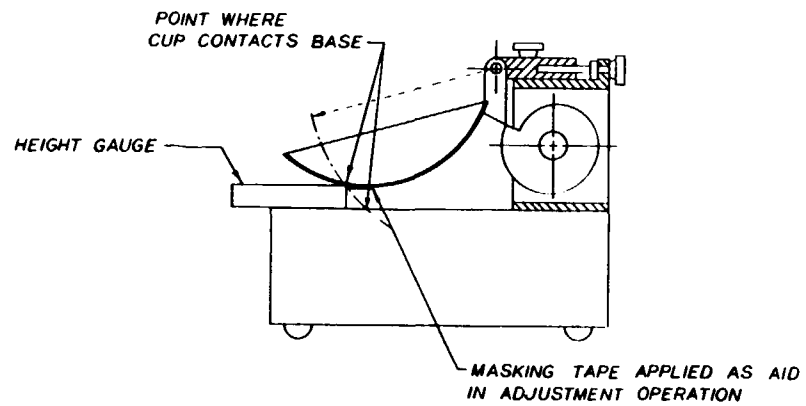


FIG. 4 Calibration for Height of Drop

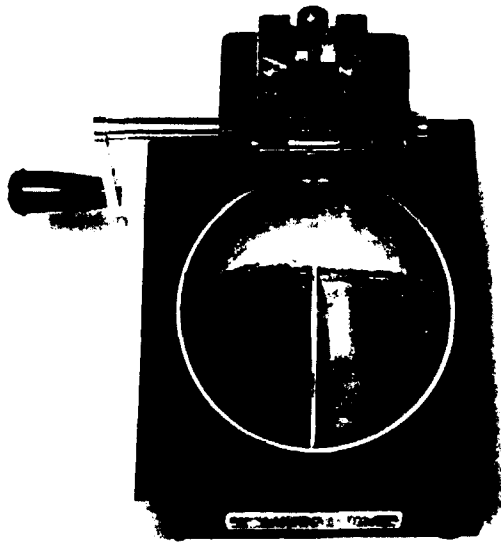


FIG. 5 Grooved Soil Pat in Liquid Limit Device

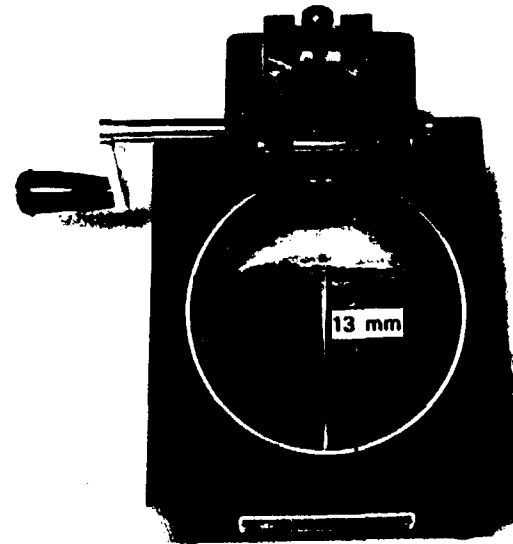


FIG. 6 Soil Pat After Groove Has Closed

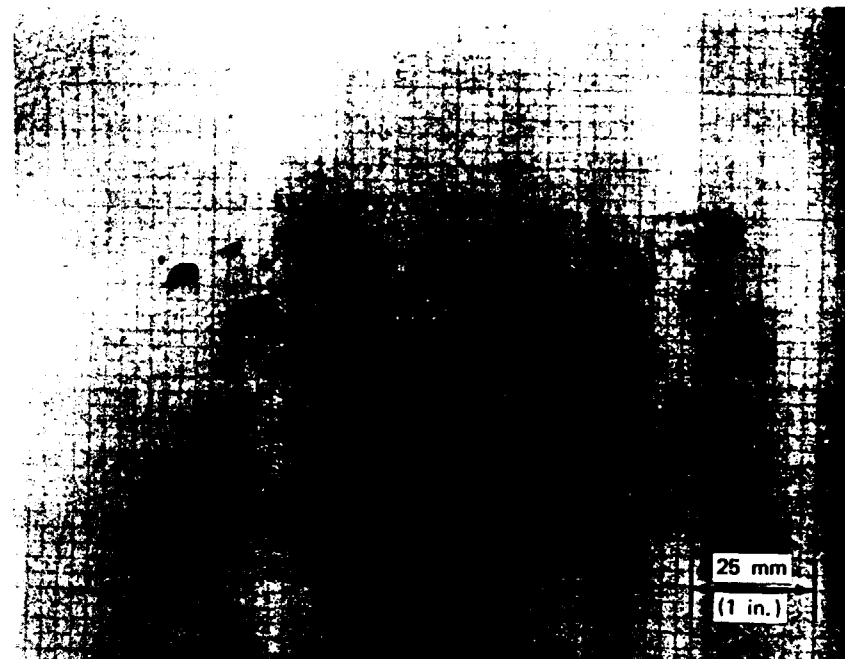


FIG. 7 Lean Clay Soil at the Plastic Limit

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Standard Test Methods for MOISTURE-DENSITY RELATIONS OF SOILS AND SOIL- AGGREGATE MIXTURES USING 10-lb (4.54-kg) RAMMER AND 18-in. (457-mm) DROP¹

This standard is issued under the fixed designation D 1557; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index Specifications and Standards.

1. Scope

1.1 These laboratory compaction methods cover the determination of the relationship between the moisture content and density of soils and soil-aggregate mixtures (Note 1) when compacted in a mold of a given size with a 10-lb (4.54-kg) rammer dropped from a height of 18 in. (457 mm) (Note 2). Four alternative procedures are provided as follows:

1.1.1 *Method A*—A 4-in. (101.6-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.2 *Method B*—A 6-in. (152.4-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.3 *Method C*—A 6-in. (152.4-mm) mold; material passing a $\frac{3}{4}$ -in. (19.0-mm) sieve; and

1.1.4 *Method D*—A 6-in. (152.4-mm) mold; material passing a $\frac{3}{4}$ -in. (19.0-mm) sieve, corrected by replacement for material retained on a $\frac{3}{4}$ -in. sieve.

NOTE 1—Soils and soil-aggregate mixtures should be regarded as natural occurring fine- or coarse-grained soils or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as silt, gravel, or crushed rock.

NOTE 2—These laboratory compaction test methods when used on soils and soil-aggregates which are not free-draining will, in most cases, establish a well-defined optimum moisture content and maximum density (see Section 7). However, for free-draining soils and soil-aggregate mixtures, these methods will not, in many cases, produce a well-defined moisture-density relationship and the maximum density obtained will generally be less than that obtained by vibratory methods.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions

of Section 5 shall govern.

2. Applicable Documents

2.1 ASTM Standards:

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate²

D 854 Test Method for Specific Gravity of Soils³

D 2168 Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors³

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures³

D 2487 Test Method for Classification of Soils for Engineering Purposes³

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)³

E 11 Specification for Wire-Cloth Sieves for Testing Purposes⁴

3. Apparatus

3.1 *Molds*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 3.1.1 or 3.1.2. The molds may be the "split" type consisting either of two half-round sections or a section of pipe split along one element.

¹ These methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock.

Current edition approved April 27, 1978. Published July 1978. Originally published as D 1557 - 58 T. Last previous edition D 1557 - 70.

² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 04.08.

⁴ Annual Book of ASTM Standards, Vols 04.01, 04.02, 04.05.05, and 14.02.

which can be securely locked together to form a cylinder meeting the requirements of this section. The molds may also be the "taper" type, providing the internal diameter taper is uniform and is not more than 0.200 in./linear in. (16.7 mm/linear m) of mold height. Each mold shall have a base plate assembly and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached to or detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 1 in. (25 mm) which may include an upper section that flares out to form a funnel providing there is at least a $\frac{3}{4}$ -in. (19-mm) straight cylindrical section beneath it.

3.1.1 *Mold*, 4.0 in. (101.6 mm) in diameter, having a capacity of $\frac{1}{160} \pm 0.0004$ ft³ (9.44 ± 11 cm³) and conforming to Fig. 1.

3.1.2 *Mold*, 6.0 in. (152.4 mm) in diameter, having a capacity of $\frac{1}{110.33} \pm 0.0009$ ft³ (2124 ± 25 cm³) and conforming to Fig. 2.

3.1.3 The average internal diameter, height, and volume of each mold shall be determined before initial use and at intervals not exceeding 1000 times the mold is filled. The mold volume shall be calculated from the average of at least six internal diameter and three height measurements made to the nearest 0.001 in. (0.02 mm), or from the amount of water required to completely fill the mold, corrected for temperature variance in accordance with Table 1. If the average internal diameter and volume are not within the tolerances shown in Figs. 1 or 2, the mold shall not be used. The determined volume shall be used in computing the required densities.

3.2 *Rammer*—The rammer may be either manually operated (see 3.2.1) or mechanically operated (see 3.2.2). The rammer shall fall freely through a distance of $18.0 \pm \frac{1}{16}$ in. (457.2 ± 1.6 mm) from the surface of the specimen. The manufactured weight of the rammer shall be 10.00 ± 0.02 lb (4.54 ± 0.01 kg). The specimen contact face shall be flat.

3.2.1 *Manual Rammer*—The specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be equipped with a guidesleeve which shall provide sufficient clearance so that the free fall of the rammer shaft and head will not be restricted. The guidesleeve

shall have four vent holes at each end (eight holes total) located with centers $\frac{3}{4} \pm \frac{1}{16}$ in. (19.0 ± 1.6 mm) from each end and spaced 90 deg apart. The minimum diameter of the vent holes shall be $\frac{1}{8}$ in. (9.5 mm).

3.2.2 *Mechanical Rammer*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03 in. (2.5 ± 0.8 mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. When used with the 4.0-in. (101.6-mm) mold, the specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). When used with the 6.0-in. (152.4-mm) mold, the specimen contact face shall have the shape of a section of a circle of a radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm). The sector face rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen. The mechanical rammer shall be calibrated and adjusted, as necessary, in accordance with 3.2.3.

3.2.3 *Calibration and Adjustment*—The mechanical rammer shall be calibrated, and adjusted as necessary, before initial use; near the end of each period during which the mold was filled 1000 times; before reuse after anything, including repairs, which may affect the test results significantly; and whenever the test results are questionable. Each calibration and adjustment shall be in accordance with Methods D 2168.

3.3 *Sample Extruder* (optional)—A jack, frame, or other device adapted for the purpose of extruding compacted specimens from the mold.

3.4 *Balances*—A balance or scale of at least 20-kg capacity sensitive to ± 1 g and a balance of at least 1000-g capacity sensitive to ± 0.01 g.

3.5 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, capable of maintaining a temperature of $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$) for determining the moisture content of the compacted specimen.

3.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The scraping edge shall have a straightness tolerance of ± 0.005 in. (± 0.13 mm) and shall be beveled if it is thicker than $\frac{1}{8}$ in. (3 mm).

3.7 Sieves, 3-in. (75-mm), $\frac{3}{4}$ -in. (19.0-mm), and No. 4 (4.75-mm), conforming to the requirements of Specification E 11.

3.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

4. Procedure

4.1 *Specimen Preparation*—Select a representative portion of quantity adequate to provide, after sieving, an amount of material weighing as follows: Methods A—25 lb (11 kg); Methods B, C, and D—50 lb (23 kg). Prepare specimens in accordance with either 4.1.1 through 4.1.3 or 4.1.4.

4.1.1 *Dry Preparation Procedure*—If the sample is too damp to be friable, reduce the moisture content by drying until the material is friable; see 4.1.2. Drying may be in air or by the use of a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). After drying (if required), thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of the particles. Pass the material through the specified sieve as follows: Methods A and B—No. 4 (4.75-mm); Methods C and D— $\frac{3}{4}$ -in. (19.0-mm). Correct for oversize material in accordance with Section 5, if Method D is specified.

4.1.2 Whenever practicable, soils classified as ML, CL, OL, GC, SC, MH, CH, OH and PT by Test Method D 2487 shall be prepared in accordance with 4.1.4.

4.1.3 Prepare a series of at least four specimens by adding increasing amounts of water to each sample so that the moisture contents vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). Thoroughly mix each specimen to ensure even distribution of moisture throughout and then place in a separate covered container and allow to stand prior to compaction in accordance with Table 2. For the purpose of selecting a standing time, it is not required to perform the actual classification procedures described in Test Method D 2487 (except in the case of referee

testing), if previous data exist which provide a basis for classifying the sample.

4.1.4 *Moist Preparation Method*—The following alternate procedure is recommended for soils classified as ML, CL, OL, GC, SC, MH, CH, OH and PT by Test Method D 2487. Without previously drying the sample, pass it through the $\frac{3}{4}$ -in. (19.0-mm) and No. 4 (4.75-mm) sieves. Correct for oversize material in accordance with Section 5, if Method D is specified. Prepare a series of at least four specimens having moisture contents that vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). To obtain the appropriate moisture content of each specimen, the addition of a predetermined amount of water (see 4.1.3) or the removal of a predetermined amount of moisture by drying may be necessary. Drying may be in air or by the use of a drying apparatus such that the temperature of the specimen does not exceed 140°F (60°C). The prepared specimens shall then be thoroughly mixed and stand, as specified in 4.1.3 and Table 2, prior to compaction.

NOTE 3—With practice, it is usually possible to visually judge the point of optimum moisture closely enough so that the prepared specimens will bracket the point of optimum moisture content.

4.2 *Specimen Compaction*—Select the proper compaction mold, in accordance with the method being used, and attach the mold extension collar. Compact each specimen in five layers of approximately equal height. Each layer shall receive 25 blows in the case of the 4-in. (101.6-mm) mold; each layer shall receive 56 blows in the case of the 6-in. (152.4-mm) mold. The total amount of material used shall be such that the fifth compacted layer is slightly above the top of the mold, but not exceeding $\frac{1}{4}$ in. (6 mm). During compaction the mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete weighing not less than 200 lb (91 kg).

4.2.1 In operating the manual rammer, care shall be taken to avoid rebound of the rammer from the top end of the guidesleeve.

The guidesleeve shall be held steady and within 5 deg of the vertical. The blows shall be applied at a uniform rate not exceeding approximately 1.4 s per blow and in such a manner as to provide complete and uniform coverage of the specimen surface.

4.2.2 *Mold Sizes*—The mold size used shall be as follows: Method A, 4-in. (101.6-mm); Methods B, C, and D 6-in. (152.4-mm).

4.2.3 Following compaction, remove the extension collar; carefully trim the compacted specimen even with the top of the mold by means of the straightedge and determine the mass of the specimen. Divide the mass of the compacted specimen and mold, minus the mass of the mold, by the volume of the mold (see 3.1.3). Record the result as the wet density, γ_m , in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

4.2.4 Remove the material from the mold. Determine moisture content in accordance with Method D 2216, using either the whole compacted specimen or alternatively a representative specimen of the whole specimen. The whole specimen must be used when the permeability of the compacted specimen is high enough so that the moisture content is not distributed uniformly throughout. If the whole specimen is used, break it up to facilitate drying. Obtain the representative specimen by slicing the compacted specimen axially through the center and removing 100 to 500 g of material from one of the cut faces.

4.2.5 Repeat 4.2 through 4.2.4 for each specimen prepared.

5. Oversize Corrections

5.1 If 30 % or more of the sample is retained on a $\frac{3}{4}$ -in. (19.0-mm) sieve, then none of the methods described under these methods shall be used for the determination of either maximum density or optimum moisture content.

5.2 *Methods A and B*—The material retained on the No. 4 (4.75-mm) sieve is discarded and no oversize correction is made. However, it is recommended that if the amount of material retained is 7 % or greater, Method C be used instead.

5.3 *Method C*—The material retained on the $\frac{3}{4}$ -in. (19.0-mm) sieve is discarded and no oversize correction is made. However, if

the amount of material retained is 10 % or greater, it is recommended that Method D be used instead.

5.4 Method D:

5.4.1 This method shall not be used unless the amount of material retained on the $\frac{3}{4}$ -in. (19.0-mm) sieve is 10 % or greater. When the amount of material retained on the $\frac{3}{4}$ -in. sieve is less than 10 %, use Method C.

5.4.2 Pass the material retained on the $\frac{3}{4}$ -in. (19.0-mm) sieve through a 3-in. or 75-mm sieve. Discard the material retained on the 3-in. sieve. The material passing the 3-in. sieve and retained on the $\frac{3}{4}$ -in. sieve shall be replaced with an equal amount of material passing a $\frac{3}{4}$ -in. sieve and retained on a No. 4 (4.75-mm) sieve. The material for replacement shall be taken from an unused portion of the sample.

6. Calculations

6.1 Calculate the moisture content and the dry density of each compacted specimen as follows:

$$w = [(A - B)/(B - C)] \times 100$$

and

$$\gamma_d = [\gamma_m/(w + 100)] \times 100$$

where:

w = moisture content in percent of the compacted specimens,

A = mass of contained and moist specimen,

B = mass of container and oven-dried specimen,

C = mass of container,

γ_d = dry density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen, and

γ_m = wet density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

7. Moisture-Density Relationship

7.1 From the data obtained in 6.1, plot the dry density values as ordinates with corresponding moisture contents as abscissas. Draw a smooth curve connecting the plotted points. Also draw a curve termed the "curve of complete saturation" or "zero air voids curve" on this plot. This curve represents the relationship between dry density and corresponding moisture contents when the voids are completely filled with water. Values of dry density and

corresponding moisture contents for plotting the curve of complete saturation can be computed using the following equation:

$$w_{\text{sat}} = [(62.4/\gamma_d) - (1/G_s)] \times 100$$

where:

w_{sat} = moisture content in percent for complete saturation,

γ_d = dry density in pounds per cubic foot (or kilograms per cubic metre),

G_s = specific gravity of the material being tested (see Note 4), and

62.4 = density of water in pounds per cubic foot (or kilograms per cubic metre).

NOTE 4—The specific gravity of the material can either be assumed or based on the weighted average values of: (a) the specific gravity of the material passing the No. 4 (4.75-mm) sieve in accordance with Test Method D 854; and (b) the apparent specific gravity of the material retained on the No. 4 (4.75-mm) sieve in accordance with Test Method C 127.

7.2 Optimum Moisture Content, w_o —The moisture content corresponding to the peak of the curve drawn as directed in 7.1 shall be termed the “optimum moisture content.”

7.3 *Maximum Density, γ_{\max}* —The dry density in pounds per cubic foot (or kilograms per cubic metre) of the sample at "optimum moisture content" shall be termed "maximum density."

8. Report

8.1 The report shall include the following:

TABLE 1 Volume of Water per Gram based on Temperature¹

Temperature, °C (°F)	Volume of Water, ml/g
12 (53.6)	1.00048
14 (57.2)	1.00073
16 (60.8)	1.00103
18 (64.4)	1.00138
20 (68.0)	1.00177
22 (71.6)	1.00221
24 (75.2)	1.00268
26 (78.8)	1.00320
28 (82.4)	1.00375
30 (86.0)	1.00435
32 (89.6)	1.00497

^a Values other than shown may be obtained by referring to the *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, OH.

8.1.1 Method used (Method A, B, C, or D).

8.1.2 Optimum moisture content.

8.1.3 Maximum density.

8.1.4 Description of rammer (whether manual or mechanical).

8.1.5 Description of appearance of material used in test, based on Practice D 2488 (Test Method D 2487 may be used as an alternative).

8.1.6 Origin of material used in test.

8.1.7 Preparation procedure used (moist or dry).

9. Precision

9.1 Criteria for judging the acceptability of the maximum density and optimum moisture content test results are given in Table 3. The standard deviation s is calculated from the equation:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

where:

n = number of determinations:

x = individual value of each determination;
and

\bar{x} = numerical average of the determinations.

9.2 Criteria for assigning standard deviation values for single-operator precision are not available at the present time.

TABLE 2 Dry Preparation Method—Standing Times

Classification D 2487	Minimum Standing Time, h
GW, GP, SW, SP	no requirement
GM, SM	3
ML, CL, OL, GC, SC	18
MH, CH, OH, PT	36

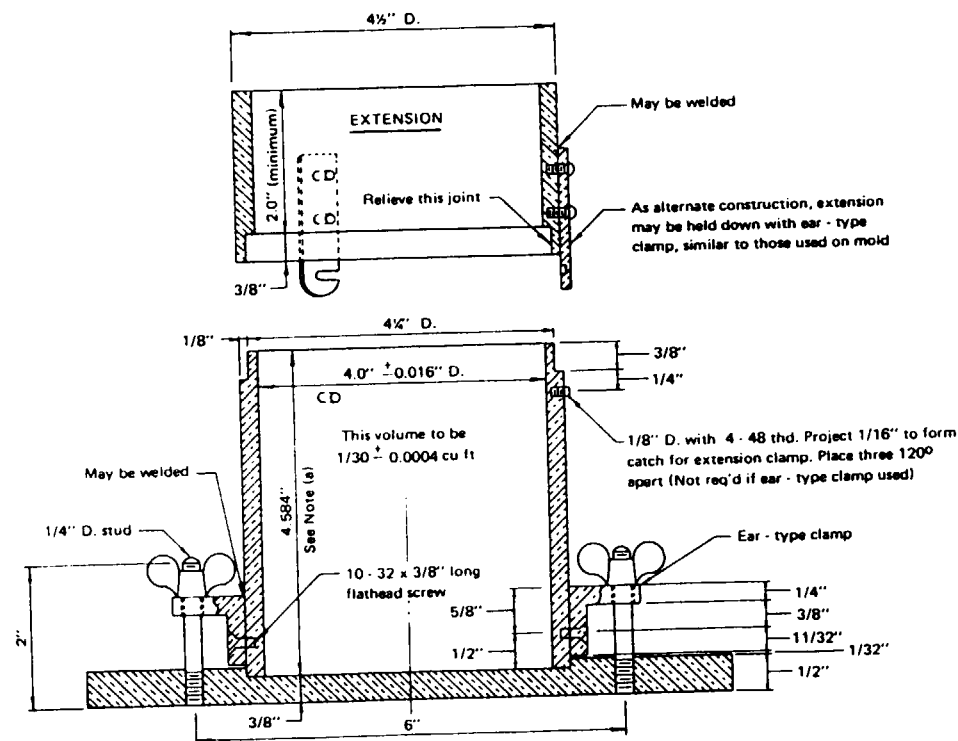
TABLE 4 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
$\frac{1}{32}$	0.8
$\frac{1}{16}$	1.6
$\frac{1}{8}$	3.2
$\frac{1}{4}$	6.4
$\frac{11}{32}$	8.7
$\frac{3}{8}$	9.5
$\frac{1}{2}$	12.7
$\frac{5}{8}$	15.9
2	50.8
$2\frac{1}{2}$	63.5
4	101.6
$4\frac{1}{4}$	108.0
$4\frac{1}{2}$	114.3
4.584	116.43
6	152.4
$6\frac{1}{2}$	165.1
8	203.2
ft ³	cm ³
$\frac{1}{30}$	944
0.004	11
$\frac{1}{15.333}$	2124
0.0009	25

TABLE 3 Precision

	Standard Deviation, s	Acceptable Range of Two Results, Expressed as Percent of Mean Value ¹
<i>Single-operator precision:</i>		
Maximum density	...	1.9
Optimum moisture content	...	9.5
<i>Multilaboratory precision:</i>		
Maximum density	±1.66	4.0
Optimum moisture content	±0.86	15.0

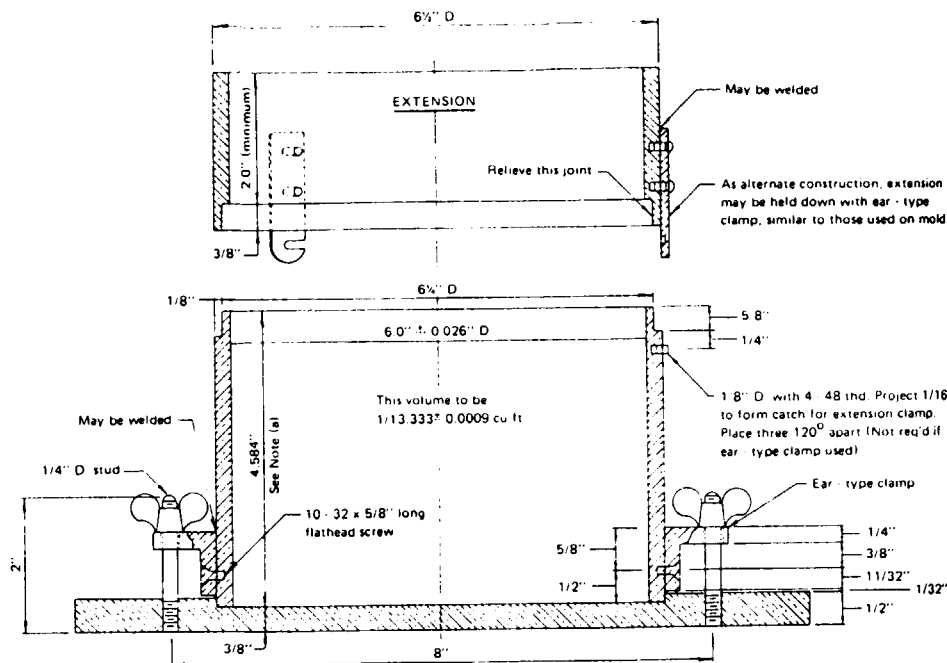
⁴ This column indicates a limiting range of values which should not be exceeded by the difference between any two results, expressed as a percentage of the average value. In cooperative test programs it has been determined that 95 % of the tests do not exceed the limiting acceptable ranges shown below. All values shown in this table are based on average test results from a variety of different soils and are subject to future revision.



NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold, 4.0-in. for Soil Tests (see Table 4 for metric equivalents).



NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 2 Cylindrical Mold, 6.0-in. for Soil Tests (see Table 4 for metric equivalents).

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Standard Test Method for MOISTURE CONTENT PENETRATION RESISTANCE RELATIONSHIPS OF FINE-GRAINED SOILS¹

This standard is issued under the fixed designation D 1558; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method is for establishing the moisture-penetration resistance relationships of fine-grained soils as determined by the soil penetrometer.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 ASTM Standards:

D698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop²

D2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures²

E 380 Metric Practice³

3. Significance and Use

3.1 This test method is used with Methods A and B of Test Methods D 698 to develop relationships between moisture content, density, and penetration resistance. These relationships are used with a previously prepared family of moisture-penetration curves as a rapid field test to determine the approximate amount of moisture in the soil.

NOTE 1—When a penetration-resistance measurement of material in place is compared at a given moisture content with penetration-density curves prepared at a specified compactive effort, an approximate check of compaction (density) may be obtained.

3.2 Penetration resistance determinations are not reliable for very dry molded soil specimens or very granular soils.

4. Apparatus

4.1 *Moisture-Density Apparatus*, conforming to the requirements prescribed in Test Methods D 698.

4.2 *Soil Penetrometer*—A soil penetrometer (Fig. 1) consisting of a special spring dynamometer with pressure-indicating scale on the stem of the handle. The pressure scale shall be graduated to 90 lb in 2-lb divisions with a line encircling the stem at each 10-lb interval, or graduated to 40 kg in 1-kg divisions with a line encircling the stem at each 5-kg interval. A sliding ring on the stem shall indicate the maximum pressure obtained in the test.

4.3 *Set of Penetrometer Needles*—Each penetrometer needle (Fig. 1) shall consist of a shank with a head of known end area. The set of interchangeable needles shall include the sizes given in Table 1. The needle shank shall have graduations inscribed at intervals of 1/2 in. (10

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

Current edition approved May 25, 1984. Published July 1984. Originally published as D 1558 - 58. Last previous edition D 1558 - 71 (1977).

² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 14.02. Excerpts in all volumes.

ENGINEER MANUAL

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EM 1110-2-1906

30 November 1970

ENGINEERING AND DESIGN

LABORATORY SOILS TESTING



**HEADQUARTERS, DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS**

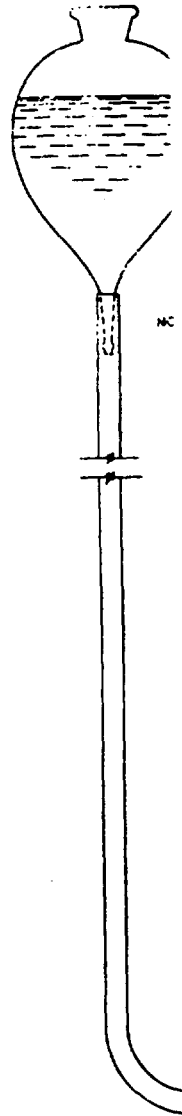
the same as those described previously for each test.

6. PERMEABILITY TEST WITH PRESSURE CHAMBER. In the permeability test with a pressure chamber, see Figure 7, a cylindrical specimen is confined in a rubber membrane and subjected to an external hydrostatic pressure during the permeability test. The advantages of this type of test are: (a) leakage along the sides of the specimen, which would occur if the specimen were tested in a permeameter, is prevented, and (b) the specimen can be tested under conditions of loading expected in the field. The test is applicable primarily to cohesive soils in the undisturbed, remolded, or compacted state. Complete saturation of the specimen, if it is not fully saturated initially, is practically impossible. Consequently, this test should be used only for soils that are fully saturated, unless values of permeability are purposely desired for soils in an unsaturated condition. The permeability test with the pressure chamber is usually performed as a falling-head test.

The permeability specimens for use in the pressure chamber generally should be 2.8 in. in diameter, as rubber membranes and equipment for cutting and trimming specimens of this size are available for triaxial testing apparatus (see Appendix X, TRIAXIAL COMPRESSION TESTS). A specimen length of about 4 in. is adequate. (The dimensions of a test specimen may be varied if equipment and supplies are available to make a suitable test setup.) The pressure in the chamber should not be less than the maximum head on the specimen during the test. The other test procedure and computations are the same as those described for the falling-head test. The linear relation between permeability and void ratio on a semilogarithmic plot as shown in Figure 6 is usually not applicable to fine-grained soils, particularly when compacted. Other methods of presenting permeability-void ratio data may be desirable.

7. PERMEABILITY TESTS WITH BACK PRESSURE.

a. Description. Gas bubbles in the pores of a compacted or undisturbed specimen of fine-grained soil will invalidate the results of the



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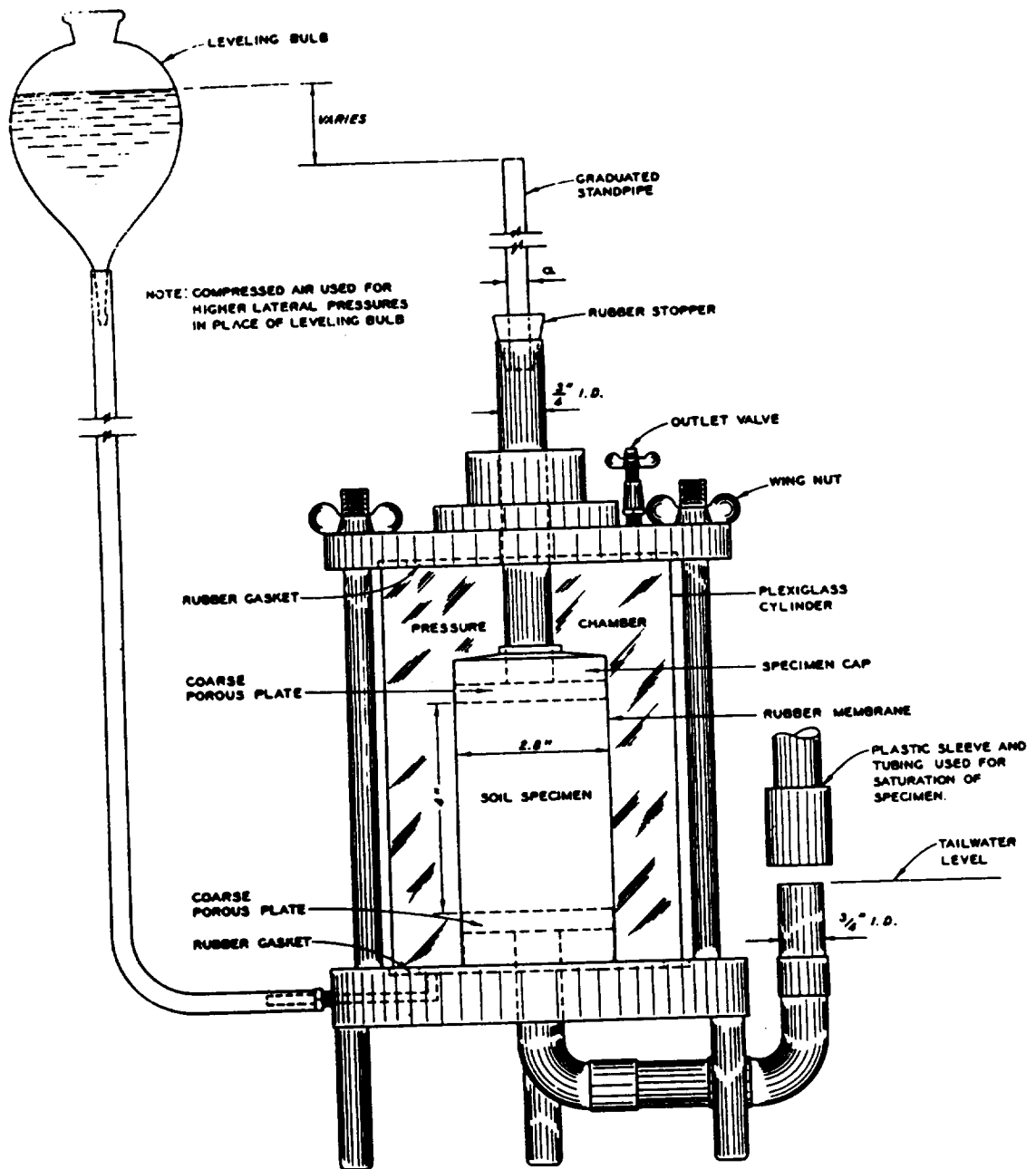


Figure 7. Pressure chamber for permeability test

permeability tests described in the preceding paragraphs. It is known that an increase in pressure will cause a reduction in volume of gas bubbles and also an increased weight of gas dissolved in water. To each degree of saturation there corresponds a certain additional pressure (back pressure) which, if applied to the pore fluid of the specimen, will cause complete saturation. The permeability test with back pressure is performed in a pressure chamber such as that shown in Figure 8, utilizing equipment that permits increasing the chamber pressure and pore pressure simultaneously, maintaining their difference constant. The method is generally applicable to fine-grained soils that are not fully saturated. Apparatus and procedures have been described by A. Casagrande† and L. Bjerrum and J. Huder‡

b. Procedure (see Fig. 8). The procedure shall consist of the following steps:

(1) After having determined the dimensions and wet weight of the test specimen, place it in the triaxial apparatus, using the same procedure as for setting up a specimen for an R triaxial test with pore pressure measurements except that filter strips should not be used (see para 7, APPENDIX X, TRIAXIAL COMPRESSION TESTS).

(2) Saturate the specimen and verify 100 percent saturation using the procedure described in paragraph 7b, APPENDIX X, TRIAXIAL COMPRESSION TESTS. Burette "A" is utilized during this operation.

(3) With the drainage valves closed, increase the chamber

† Casagrande, A., "Third Progress Report on Investigation of Stress Deformation and Strength Characteristics of Compacted Clays," Soil Mechanics Series No. 70, Nov 1963, Harvard University, Cambridge, Mass., pp 30 and 31.

‡ Bjerrum, L. and Huder, J., "Measurement of the Permeability of Compacted Clays," Proceedings, Fourth International Conference on Soil Mechanics and Foundation Engineering, London, Vol 1, Aug 1957, pp 6-8.

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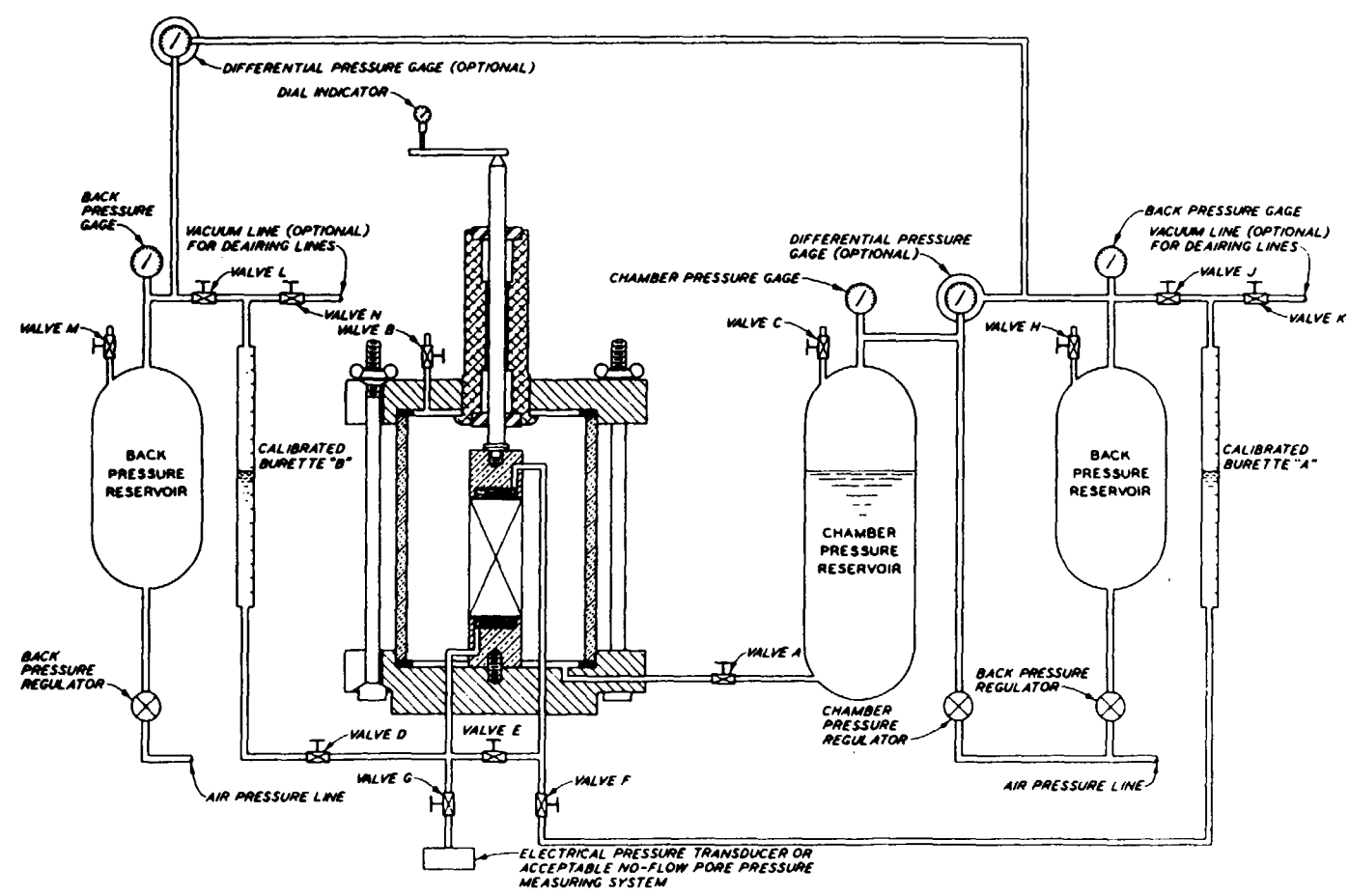


Figure 8. Schematic diagram of typical triaxial compression apparatus for permeability tests with back pressure

VII-20

pressure to attain the desired effective consolidation pressure (chamber pressure minus back pressure). At zero elapsed time, open valves E and F.

(4) Record time, dial indicator reading, and burette reading at elapsed times of 0, 15, and 30 sec, 1, 2, 4, 8, and 15 min, and 1, 2, 4, and 8 hr, etc. Plot the dial indicator readings and burette readings on an arithmetic scale versus elapsed time on a log scale. When the consolidation curves indicate that primary consolidation is complete, close valves E and F.

(5) Apply a pressure to burette B greater than that in burette A. The difference between the pressures in burettes B and A is equal to the head loss h ; h divided by the height of the specimen after consolidation, L , is the hydraulic gradient. The difference between the two pressures should be kept as small as practicable, consistent with the requirement that the rate of flow be large enough to make accurate measurements of the quantity of flow within a reasonable period of time. Because the difference in the two pressures may be very small in comparison to the pressures at the ends of the specimen, and because the head loss must be maintained constant throughout the test, the difference between the pressures within the burettes must be measured accurately; a differential pressure gage is very useful for this purpose. The difference between the elevations of the water within the burettes should also be considered (1 in. of water = 0.036 psi of pressure).

(6) Open valves D and F. Record the burette readings at any zero elapsed time. Make readings of burettes A and B and of temperature at various elapsed times (the interval between successive readings depends upon the permeability of the soil and the dimensions of the specimen). Plot arithmetically the change in readings of both burettes versus time. Continue making readings until the two curves become parallel and straight over a sufficient length of time to accurately determine the rate of flow (slope of the curves).

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(7) If it is desired to determine the permeability at several void ratios, steps 3 through 6 can be repeated, using different consolidation pressures in step 3.

(8) At the end of the permeability determinations, close all drainage valves and reduce the chamber pressure to zero; disassemble the apparatus.

(9) Determine the wet and dry weights of the specimen.

c. Computations. The computations consist of the following steps.

(1) Compute the test void ratios as outlined in paragraph 3e(1).

(2) Computations of coefficients of permeability are the same as those described for the constant-head permeability test.

8. PERMEABILITY TESTS WITH CONSOLIDOMETER. A permeability test in a consolidometer (see Appendix VIII, CONSOLIDATION TEST) is essentially similar to that conducted in a pressure chamber, except that the specimen is placed within a relatively rigid ring and is loaded vertically. The test can be used as an alternate to the permeability test in the pressure chamber. The test is applicable primarily to cohesive soils in a fully saturated condition. Testing is usually performed under falling-head conditions.

A schematic diagram of the consolidation apparatus set up for a falling-head permeability test is shown in Figure 9. Identifying information for the specimen and subsequent test data are entered on a data sheet (Plate VII-3 is a suggested form). The specimen should be placed in the specimen ring and the apparatus assembled as outlined under Appendix VIII, CONSOLIDATION TEST. The specimen is consolidated under the desired load and the falling-head test is performed as previously described. The

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to those used in the R test), apply 3-psi chamber pressure to the specimen with all drainage valves closed. Allow a minimum of 30 min for stabilization of the specimen pore water pressure, measure ΔH , and begin back-pressure procedures as given in paragraphs 7b(2) through 7b(5). After verification of saturation, and remeasurement of ΔH , close all drainage lines leading to the back pressure and pore water measurement apparatus. Holding the maximum applied back pressure constant, increase the chamber pressure until the difference between the chamber pressure and the back pressure equals the desired effective confining pressure (see paragraph 5a(5)). Then proceed as outlined in paragraphs 5a(6) through 5a(11).

7. R TEST. All specimens must be completely saturated before application of the deviator stress in the R test. A degree of saturation over 98 percent can be considered to represent a condition of essentially complete saturation; if pore water pressures are to be measured during shear, however, the specimens must be 100 percent saturated. Computations of

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Appendix X

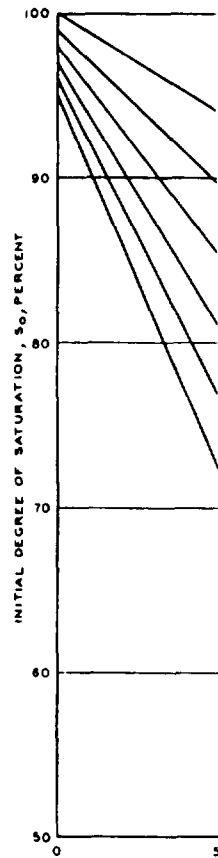
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the degree of saturation based on changes of volume and water content are often imprecise, so complete saturation of a specimen should be assumed only when an increase of the chamber fluid pressure will cause an immediate and equal increase of pressure in the pore water of the specimen. In general, it is preferable to saturate the soil after the specimens have been prepared, encased in membranes, and placed within the compression chamber, using back pressure. A back pressure is an artificial increase of the pore water pressure which will increase the degree of saturation of a specimen by forcing pockets of air into solution in the pore water. The back pressure is applied to the pore water simultaneously with an equal increase of the chamber pressure so that the effective stress acting on the soil skeleton is not changed. In other words, the pressure differential across the membrane remains constant during the back pressure saturation phase. Thus, when the back pressure is increased sufficiently slowly to avoid an excessive pressure differential within the specimen itself, the degree of saturation will be increased while the volume of the specimen is maintained essentially constant. Figure 15 gives the back pressure theoretically required to produce a desired increase in saturation if there is no change in specimen volume. It is important to note that the relation shown in Figure 15 is based on an assumption that the water entering the specimen contains no dissolved air.

a. Apparatus. In addition to the apparatus described in paragraphs 3a through 3g, the following equipment are necessary for R tests utilizing back pressure for saturation:

(1) Air reservoir and regulator for controlling the back pressure, similar to those used to control the chamber pressure.

(2) Bourdon gage attached to the back pressure reservoir to measure the applied back pressure. As relatively large back pressures and chamber pressures are sometimes required, it is essential that these two pressures be measured accurately to insure that the precise



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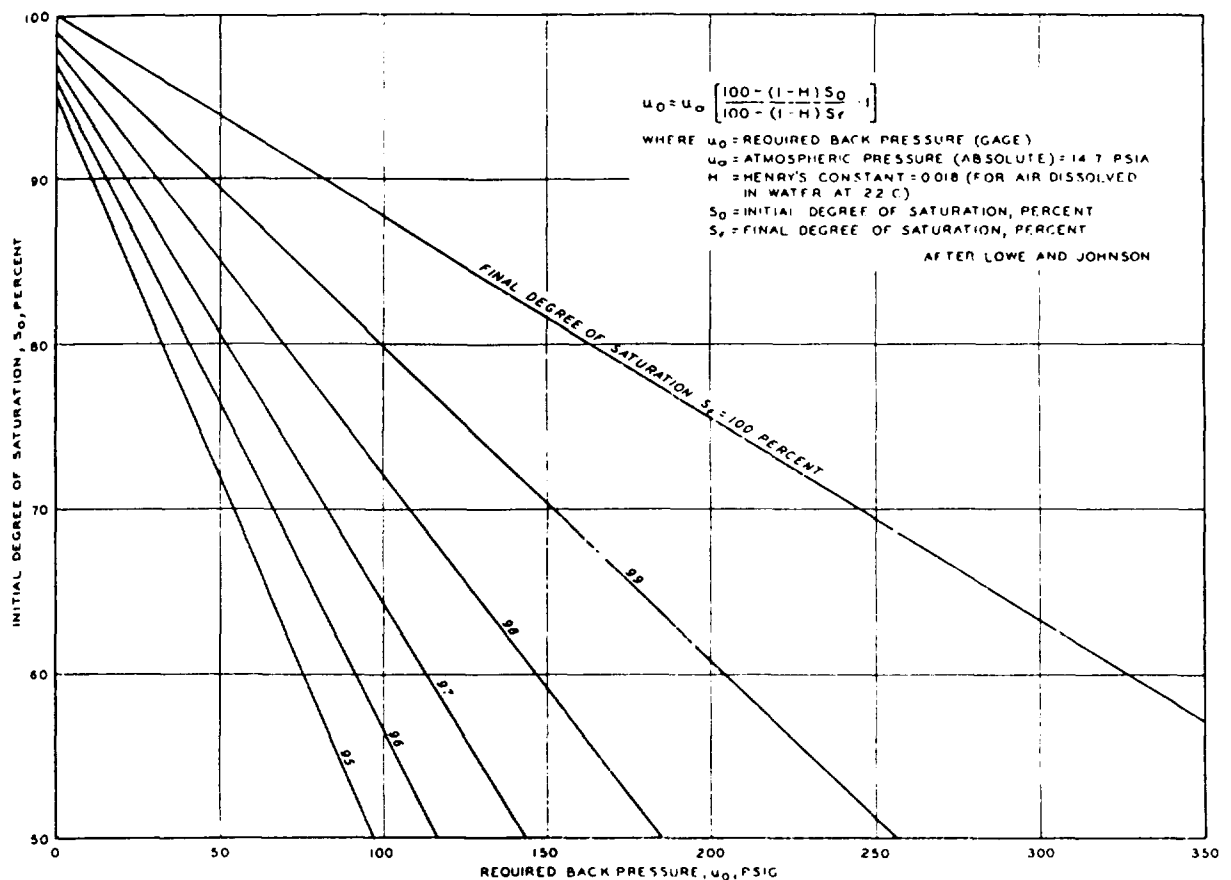


Figure 15. Back pressure required to attain various degrees of saturation

difference between them is known. A differential pressure gage† will permit this difference to be measured directly.

(3) Calibrated burette or standpipe capable of measuring volume changes to within 0.1 cc for 1.4-in.-diameter specimens, 0.5 cc for 2.8-in.-diameter specimens, and 1 cc for 6-in.-diameter specimens. This burette is connected in the back pressure line leading to the top of

† John Lowe, III, and Thaddeus C. Johnson, "Use of back pressure to increase degree of saturation of triaxial test specimens," ASCE Research Conference on Shear Strength of Cohesive Soils, University of Colorado (Boulder, Colo., June 1960).

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the specimen to measure the volume of water added to the specimen during saturation and volume changes of the specimen during consolidation. If the water added to the specimen becomes saturated with air, a higher back pressure will be required than that given in Figure 15. Therefore, precautions should be taken to minimize aeration of the saturation water by reducing the area of the air-water interface or by separating the air and water with a rolling rubber diaphragm.† A relatively long (over 6-foot) length of thick-walled, small-bore tubing between the burette and the specimen will also reduce the amount of air entering the specimen. Adequate safety precautions should be taken against breakage of the burette under high pressures.

(4) Electrical pressure transducer or no-flow indicator with which the pressure of the pore water at the bottom of the specimen can be measured without allowing a significant flow of water from the specimen. This is an extremely difficult measurement to make since even a minute flow of water will reduce the pressure in the pore water; yet the measuring device must be sensitive enough to detect small changes in pressure. Electrical pressure transducers, while relatively expensive, offer almost complete protection against flow, are simple to operate, and lend themselves to the automatic recording of test data. Several types of manually balanced pressure-measuring systems employing a no-flow indicator are being used successfully,‡ though a full discussion of their relative merits

† H. B. Seed, J. K. Mitchell, and C. K. Chan, "The strength of compacted cohesive soils," ASCE Research Conference on Shear Strength of Cohesive Soils, University of Colorado (Boulder, Colo., June 1960).

‡ Bishop and Henkel, op. cit., pp. 52-63, 206-207.

A. Andersen, L. Bjerrum, E. DiBiagio, and B. Kjaernsli, Triaxial Equipment Developed at the Norwegian Geotechnical Institute, Publication No. 21, Norwegian Geotechnical Institute (Oslo, 1957).

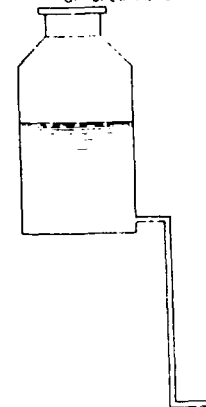
A. Casagrande and R. C. Hirschfeld, First Progress Report on Investigation of Stress-Deformation and Strength Characteristics of Compacted Clays, Soil Mechanics Series No. 61, Harvard University (Cambridge, Mass., May 1960).

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b. Procedure. The procedure for the R test utilizing back pressure for saturation shall consist of the following steps:

(1) Proceed as outlined in paragraphs 5a(1) through 5a(4), with the exception that specimen bases and caps with porous inserts and drainage connections should be used and back pressure equipment should be included as shown in Figure 16. Saturated strips of filter paper (such as Whatman's No. 54) placed beneath the membrane and extending from the base along three-fourths of the specimen length will reduce the time required for saturation and consolidation. These strips must neither overlap and form a continuous circumferential coverage of the specimen

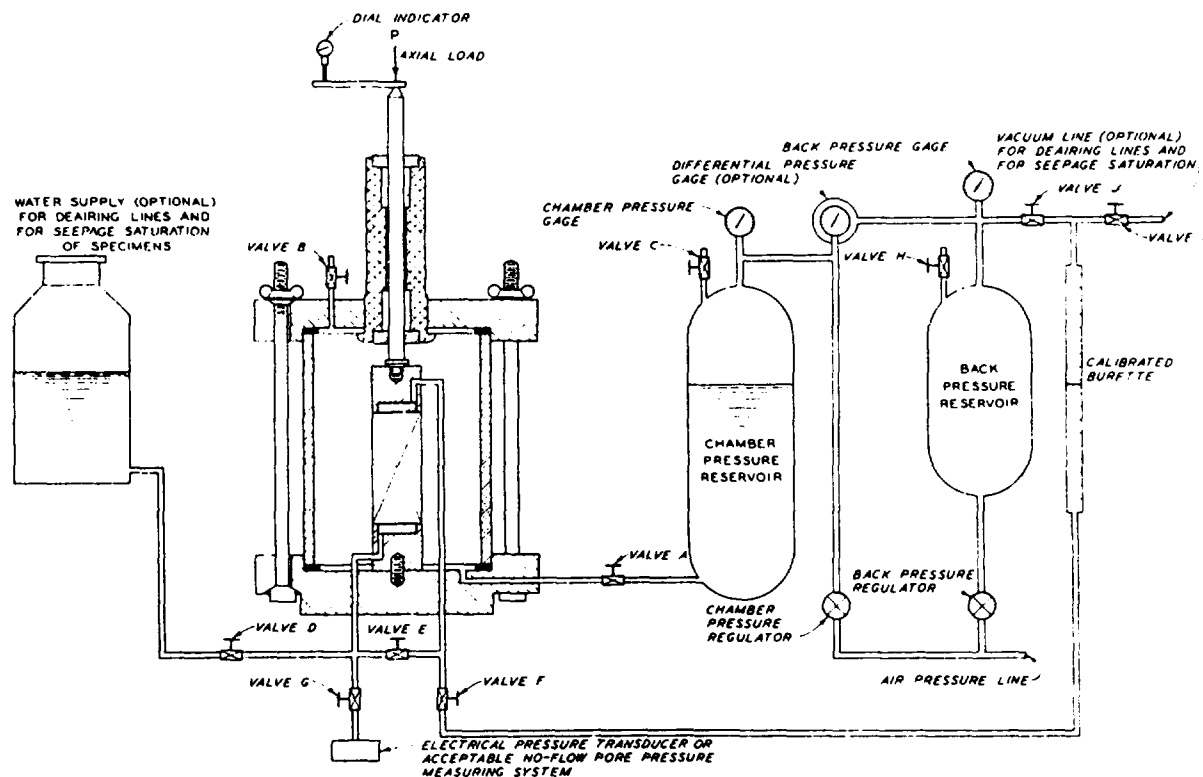


Figure 16. Schematic diagram of typical triaxial compression apparatus for R and S tests

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(2) Estimate the magnitude of the required back pressure by reference to Figure 15 or other theoretical relations. Specimens should be completely saturated before any appreciable consolidation is permitted, for ease and uniformity of saturation as well as to allow volume changes during consolidation to be measured with the burette; therefore, the difference between the chamber pressure and the back pressure should not exceed 5 psi during the saturation phase. To insure that a specimen is not prestressed during the saturation phase, the back pressure must be applied in small increments, with adequate time between increments to permit equalization of pore water pressure throughout the specimen.

(3) With all valves closed, adjust the pressure regulators to a chamber pressure of about 7 psi and a back pressure of about 2 psi. Record these pressures on the data sheet (Plate X-4). Now open valve A to apply the preset pressure to the chamber fluid and simultaneously open valve F to apply the back pressure through the specimen cap. Immediately open valve G and read and record the pore pressure at the specimen base. When the measured pore pressure becomes essentially

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constant, close valves F and G† and record the burette reading.

(4) Using the technique described in step (3), increase the chamber pressure and the back pressure in increments, maintaining the back pressure at about 5 psi less than the chamber pressure. The size of each increment might be 5, 10, or even 20 psi, depending on the compressibility of the soil specimen and the magnitude of the desired consolidation pressure. Open valve G and measure the pore pressure at the base immediately upon application of each increment of back pressure and observe the pore pressure until it becomes essentially constant. The time required for stabilization of the pore pressure may range from a few minutes to several hours depending on the permeability of the soil. Continue adding increments of chamber pressure and back pressure until, under any increment, the pore pressure reading equals the applied back pressure immediately upon opening valve G.

(5) Verify the completeness of saturation by closing valve F and increasing the chamber pressure by about 5 psi. The specimen shall not be considered completely saturated unless the increase in pore pressure immediately equals the increase in chamber pressure.

(6) When the specimen is completely saturated, hold the maximum applied back pressure constant and increase the chamber pressure until the difference between the chamber pressure and the back pressure equals the desired consolidation pressure. Open valve F and permit the specimen to consolidate (or swell) under the consolidation pressure. Valve E may be opened to allow drainage from both ends of the specimen. At increasing intervals of elapsed time (0.1, 0.2, 0.5, 1, 2, 4, 8, 15, and 30 min, 1, 2, 4, and 8 hr, etc.), observe and record (Plate X-5) the burette readings and, if practicable, the dial indicator readings (it may be necessary to force the piston down into contact with the specimen cap for each

† If an electrical pressure transducer is used to measure the pore pressure, valve G may be safely left open during the entire saturation procedure.

reading). Plot the burette readings (and dial indicator readings, if taken) versus the logarithm of elapsed time, as shown in Figure 5 of Appendix VIII, CONSOLIDATION TEST. Allow consolidation to continue until a marked reduction in slope of the curve shows that 100 percent primary consolidation has been achieved.

(7) Close valve G, unless pore pressure measurements are to be made during shear, and valves E and F, and proceed according to paragraphs 5a(6) through 5a(10), except use a rate of strain for the R test of about 0.5 percent per minute (for plastic materials) and about 0.3 percent per minute or less for brittle materials that achieve a maximum deviator stress at about 3 to 6 percent strain; the strain rate used should result in a time to maximum deviator stress of approximately 30 min. Relatively pervious soils may be sheared in 15 min. These rates of strain do not permit equalization of induced pore pressure throughout the specimen and are too high to allow satisfactory pore pressure measurements to be made at the specimen ends during shear.† Therefore, these rates of strain are applicable only to R tests in which no pore pressure measurements are made during shear. Where pore pressure measurements are made at the ends of the specimens as in \bar{R} tests, the time to reach maximum deviator stress should generally be at least 120 min; considerably longer time may be required for materials of low permeability. For brittle soils (i.e., those in which the maximum deviator stress is reached at 6 percent axial strain or less), after the maximum deviator stress has been clearly defined, the rate of strain may be increased so that the remainder of the test is completed in the same length of time as that taken to reach maximum deviator stress. However, for each group of tests in a given test program, at least 20 percent of the samples should be tested to final axial strain at rates of strain outlined in the first sentence of this paragraph.

c. Computations. The computations shall consist of the following steps:

(1) From the observed data, compute and record on the data sheet (Plate X-1) the initial water content, volume of solids, initial void

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† Bishop and Henkel, op. cit., pp. 192-204.

ratio, initial degree of saturation, and initial dry density, using the formulas previously presented.

(2) Compute the cross-sectional area of the specimen after completion of consolidation according to the formula:†

$$\text{Area of specimen after consolidation, } A_c, \text{ sq cm} = A_o \frac{H_o - 2\Delta H_o}{H_o}$$

or if the specimen is or has been completely saturated during the test, use the more accurate formula:

$$\text{Area of specimen after consolidation, } A_c, \text{ sq cm} = \frac{V_o - V_a - \Delta V_w}{H_o - \Delta H_o}$$

where V_o = initial volume of specimen, cc

V_a = initial volume of air in specimen, cc = $V_o - V_s - V_w$

$V_o - V_s - V_w$ = initial volume of specimen minus volume of solids minus initial volume of water

ΔV_w = change in volume of water in the specimen during the saturation and consolidation phases of the test, cc. This value may be computed from the change in weight of the specimen before and after the test or from the burette readings from the start of saturation on to the end of consolidation

H_o = initial height of specimen, cm

ΔH_o = change in height of specimen during consolidation, cm

(3) Using the computed dimensions of the specimen after consolidation and assuming that the water content after consolidation is the same as the final water content, compute the void ratio and degree of saturation using formulas previously presented.

(4) Compute and record on the data sheet (Plate X-2) the axial strain, the corrected area, and the deviator stress at each increment of strain, using the following formulas:

† This formula is based on the assumption that axial and radial strains are equal during consolidation.

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$$\text{Axial strain, } \epsilon = \frac{\Delta H}{H_c}$$

$$\text{Corrected area of specimen, } A_{\text{corr}}, \text{ sq cm} = \frac{A_c}{1 - \epsilon}$$

$$\text{Deviator stress, tons per sq ft} = \frac{P}{A_{\text{corr}}} \times 0.465$$

where H_c = height of specimen after consolidation, cm = $H_o - \Delta H_o$

P = net applied axial load, lb (see paragraph 5b(2))

(5) Record the time to failure on the data sheet (Plate X-2).

(6) Correct the maximum deviator stress, if necessary, for the effect of membrane restraint (see paragraph 5b(4)).

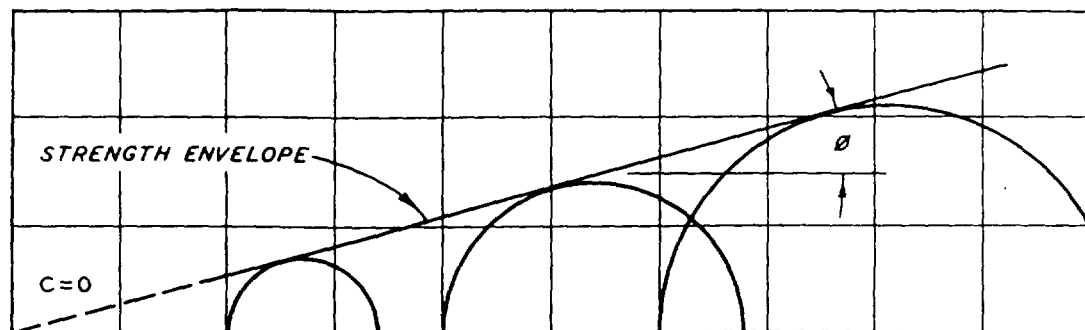
d. Presentation of Results. The results of the R test shall be presented on the report form shown as Plate X-3, as described in paragraph 5c. A sketch of each specimen after failure should be shown above the Mohr circles. If pore pressure measurements were made during shear, plot the induced pore pressure versus axial strain for each specimen below the stress-strain curves. The procedures below should be followed in drawing strength envelopes:

(1) Undisturbed specimens. For undisturbed specimens, strength envelopes should be drawn tangent to the Mohr circles as shown in Figures 17a and 17b.

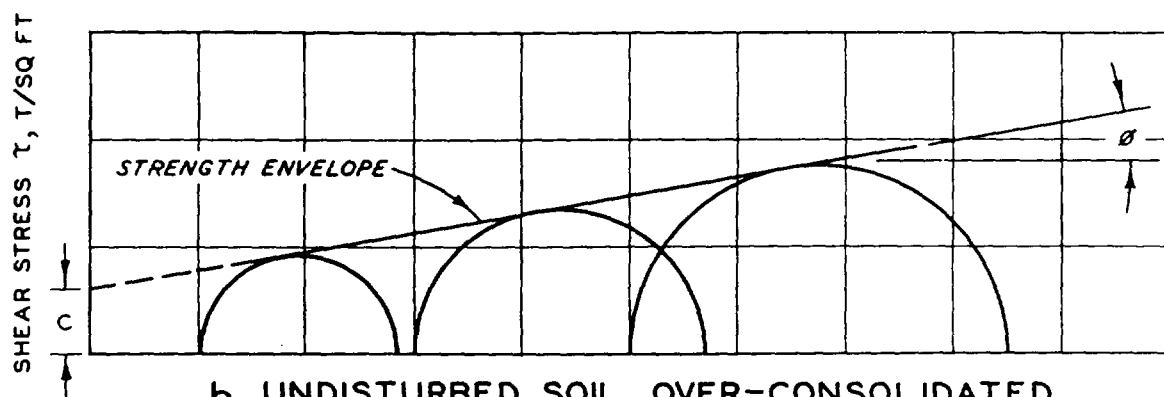
(2) Compacted specimens. For compacted specimens, strength envelopes should be drawn through points on the Mohr circles representing stresses on the failure plane as shown in Figure 17c.

8. S TEST. The S test using triaxial equipment, as a rule, shall be performed only with relatively pervious soils. The consolidation of triaxial specimens of relatively impervious soils proceeds so slowly that the time required to complete an S triaxial test inhibits its use in

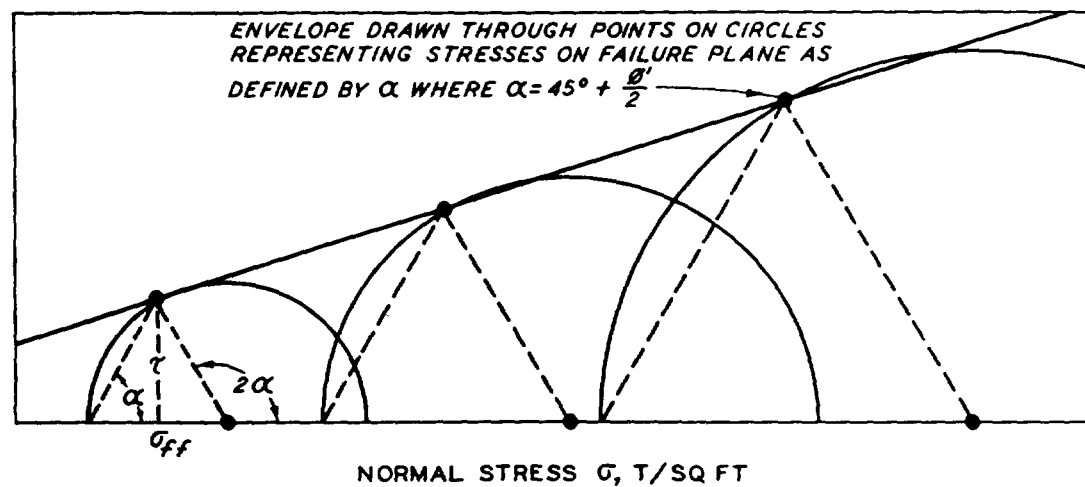
SHEAR STRESS τ , T/SQ FT



a. UNDISTURBED SOIL, NORMALLY CONSOLIDATED



b. UNDISTURBED SOIL, OVER-CONSOLIDATED



c. COMPACTED SOIL

Figure 17. Examples of strength envelopes for R tests



Standard Method for LABORATORY DETERMINATION OF WATER (MOISTURE) CONTENT OF SOIL, ROCK, AND SOIL-AGGREGATE MIXTURES¹

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers the laboratory determination of the water (moisture) content of soil, rock, and soil-aggregate mixtures by weight. For simplicity, the word "material" hereinafter refers to either soil, rock, or soil-aggregate mixtures, whichever is most applicable.

1.2 The water content of a material is defined as the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material particles.

1.3 This method does not give true representative results for: materials containing significant amounts of halloysite, montmorillonite, or gypsum minerals; highly organic soils; or, materials in which the pore water contains dissolved solids (such as salt in the case of marine deposits). For a material of the previously mentioned types, a modified method of testing or data calculation may be established to give results consistent with the purpose of the test.

2. Summary of Method

2.1 The practical application in determining the water content of a material is to determine the mass of water removed by drying the moist material (test specimen) to a constant mass in a drying oven controlled at $110 \pm 5^\circ\text{C}$ and to use this value as the mass of water in the test specimen. The mass of material remaining after oven-drying is used as the mass of the solid particles.

3. Significance and Use

3.1 For many soil types, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 The water content of a soil is used in almost every equation expressing the phase relationships of air, water, and solids in a given volume of material.

3.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limit, is used to express its relative consistency or liquidity index.

3.4 The term "water" as used in geotechnical engineering, is typically assumed to be "pore" or "free" water and not that which is hydrated to the mineral surfaces. Therefore, the water content of materials containing significant amounts of hydrated water at in-situ temperatures or less than 110°C can be misleading.

3.5 The term "solid particles" as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, etc), water-soluble matter (such as salt) and highly organic

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved May 30, 1980. Published July 1980. Originally published as D 2216 - 63 T. Last previous edition D 2216 - 71.

matter typically require special treatment or a qualified definition of water content.

4. Apparatus

4.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, and maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$ throughout the drying chamber.

4.2 *Balances*, having a precision (repeatability) of ± 0.01 g for specimens having a mass of 200 g or less, ± 0.1 g for specimens having a mass of between 200 and 1000 g, or ± 1 g for specimens having a mass greater than 1000 g.

4.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and a change in mass upon repeated heating, cooling, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g, while for specimens having a mass greater than about 200 g, containers without lids may be used (Note 1). One container is needed for each water content determination.

NOTE 1—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing.

4.4 *Desiccator*—A desiccator of suitable size (a convenient size is 200 to 250-mm diameter) containing a hydrous silica gel. This equipment is only recommended for use when containers having close-fitting lids are not used. See 7.4.1.

5. Samples

5.1 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight.

5.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as steel thin-walled tubes, paint cans, etc.) or sample bags are used.

6. Test Specimen

6.1 For water contents being determined in conjunction with another ASTM method, the method of specimen selection specified in that method controls.

6.2 The manner in which the test specimen is selected and its required mass is basic dependent on the purpose (application) of test, type of material being tested, and the type of sample (specimen from another test, tube, split-barrel, etc.). In all cases, however, representative portion of the total sample shall be selected. If a layered soil or more than one soil type is encountered, select an average portion or individual portions or both, and note which portion(s) was tested in the report of the results.

6.2.1 For bulk samples, select the test specimen from the material after it has been thoroughly mixed. The mass of moist material selected shall be in accordance with the following table:

Sieve Retaining More Than About 10 % of Sample	Recommended Minimum Mass of Moist Specimen, g
2.0 mm (No. 10) sieve	100 to 200
4.75 mm (No. 4) sieve	300 to 500
19 mm	500 to 1000
38 mm	1500 to 3000
76 mm	5000 to 10 000

6.2.2 For small (jar) samples, select a representative portion in accordance with the following procedure:

6.2.2.1 For cohesionless soils, thoroughly mix the material, then select a test specimen having a mass of moist material in accordance with the table in 6.2.1. See Note 2.

6.2.2.2 For cohesive soils, remove about 10 mm of material from the exposed periphery of the sample and slice it in half (to check if the material is layered) prior to selecting the test specimen. If the soil is layered see 6.2. The mass of moist material selected should not be less than 25 g or should be in accordance with the table in 6.2.1 if coarse-grained particles are noted. (Note 2).

6.3 Using a test specimen smaller than the minimum mass indicated previously requires discretion, though it may be adequate for the purpose of the test. A specimen having a mass less than the previously indicated value shall be noted in the report of the results.

NOTE 2—In many cases, when working with a small sample containing a relatively large coarse-grained particle, it is appropriate not to include this particle in the test specimen. If this occurs, it should be noted in the report of the results.

7. Procedure

7.1 Select representative test specimens in accordance with Section 6.

7.2 Place the moist specimen in a clean, dry container of known mass (Note 3), set the lid securely in position, and determine the mass of the container and moist material using an appropriate balance (4.2). Record these values.

7.3 Remove the lid and place the container with moist material in a drying oven maintained at $110 \pm 5^\circ\text{C}$ and dry to a constant mass (Notes 4, 5, and 6).

NOTE 3—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

NOTE 4—The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used. In most cases, drying a test specimen overnight (about 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the mass after two successive periods (greater than $\frac{1}{2}$ h) of drying indicate an insignificant change (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 5—Oven-drying at $110 \pm 5^\circ\text{C}$ does not always result in water content values related to the intended use or the basic definition especially for materials containing gypsum or other minerals having significant amounts of hydrated water or for soil containing a significant amount of organic material. In many cases, and depending on the intended use for these types of materials, it might be more applicable to maintain the drying oven at $60 \pm 5^\circ\text{C}$ or use a vacuum desiccator at a vacuum of approximately 133 Pa (10 mm Hg) and at a temperature ranging between 23 and 60°C for drying. If either of these drying methods are used, it should be noted in the report of the results.

NOTE 6—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the oven. However, this requirement is not applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

7.4 After the material has dried to constant mass remove the container from the oven and replace the lid. Allow the material and container to cool to room temperature or until the container can be handled comfortably with

bare hands and the operation of the balance will not be affected by convection currents. Determine the mass of the container and oven-dried material using the same balance as used in 7.2. Record this value.

7.4.1 If the container does not have a lid, weigh the container and material right after their temperatures are such that the operation of the balance will not be affected by convection currents or after cooling in a desiccator.

NOTE 7—Cooling in a desiccator is recommended since it prevents absorption of moisture from the atmosphere during cooling.

8. Calculation

8.1 Calculate the water content of the material as follows:

$$w = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = \frac{W_w}{W_s} \times 100$$

where:

w = water content, %,

W_1 = mass of container and moist specimen, g,

W_2 = mass of container and oven-dried specimen, g,

W_c = mass of container, g,

W_w = mass of water, g, and

W_s = mass of solid particles, g.

9. Report

9.1 The report (data sheet) shall include the following:

9.1.1 Identification of the sample (material) being tested, by boring number, sample number, test number, etc.

9.1.2 Water content of the specimen to the nearest 0.1 % or 1 %, depending on the purpose of the test.

9.1.3 Indication of test specimen having a mass less than the minimum indicated in Section 6.

9.1.4 Indication of test specimen containing more than one soil type (layered, etc).

9.1.5 Indication of the method of drying if different from oven-drying at $110 \pm 5^\circ\text{C}$.

9.1.6 Indication of any material (size and amount) excluded from the test specimen.

10. Precision and Accuracy

curacy of this test method have not yet been developed.

10.1 Requirements for the precision and ac-

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Standard Test Method for SPECIFIC GRAVITY OF SOILS¹

This standard is issued under the fixed designation D 854; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers determination of the specific gravity of soils by means of a pycnometer. When the soil is composed of particles larger than the No. 4 (4.75-mm) sieve, the method outlined in Test Method C 127 shall be followed. When the soil is composed of particles both larger and smaller than the No. 4 sieve, the sample shall be separated on the No. 4 sieve and the appropriate test method used on each portion. The specific gravity value for the soil shall be the weighted average of the two values (Note 1). When the specific gravity value is to be used in calculations in connection with the hydrometer portion of Method D 422, it is intended that the specific gravity test be made on that portion of the soil which passes the No. 10 (2.00-mm) sieve.

NOTE 1—The weighted average specific gravity should be calculated using the following equation:

$$G_{avg} = \frac{1}{\frac{R_1}{100G_1} + \frac{P_1}{100G_2}}$$

where:

G_{avg} = weighted average specific gravity of soils composed of particles larger and smaller than the No. 4 (4.75-mm) sieve,

R_1 = percent of soil particles retained on the No. 4 sieve,

P_1 = percent of soil particles passing the No. 4 sieve,

G_1 = apparent specific gravity of soil particles retained on the No. 4 sieve as determined by Test Method C 127, and

G_2 = specific gravity of soil particles passing the No. 4 sieve as determined by this test method.

1.2 The values stated in acceptable metric units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 ASTM Standards:

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate²

C 670 Practice for Preparing Precision Statements for Test Methods for Construction Materials²

D 422 Method for Particle-Size Analysis of Soils³

E 12 Definitions of Terms Relating to Density and Specific Gravity of Solids, Liquids, and Gases⁴

3. Definition

3.1 *specific gravity*—the ratio of the mass of a unit volume of a material at a stated temperature to the mass in air of the same volume of gas-free distilled water at a stated temperature (per Definitions E 12).

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

Current edition approved Nov. 28, 1983. Published January 1984. Originally issued as D 854 - 45. Last previous edition D 854 - 58 (1979).

² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 04.08.

⁴ Annual Book of ASTM Standards, Vol 15.05.

4. Significance and Use

4.1 The specific gravity of a soil is used in almost every equation expressing the phase relationship of air, water, and solids in a given volume of material.

4.2 The term "solid particles," as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not very soluble in water. Therefore, the specific gravity of materials containing extraneous matter (such as cement, lime, etc.), water-soluble matter (such as sodium chloride), and soils containing matter with a specific gravity of less than one, typically require special treatment or a qualified definition of specific gravity.

5. Apparatus

5.1 *Pycnometer*—Either a volumetric flask having a capacity of at least 100 mL or a stoppered bottle having a capacity of at least 50 mL (Note 2). The stopper shall be of the same material as the bottle, and of such size and shape that it can be easily inserted to a fixed depth in the neck of the bottle, and shall have a small hole through its center to permit the emission of air and surplus water.

NOTE 2—The use of either the volumetric flask or the stoppered bottle is a matter of individual preference, but in general, the flask should be used when a larger sample than can be used in the stoppered bottle is needed due to maximum grain size of the sample.

5.2 *Balance*—Either a balance sensitive to 0.01 g for use with the volumetric flask, or a balance sensitive to 0.001 g for use with the stoppered bottle.

6. Calibration of Pycnometer

6.1 The pycnometer shall be cleaned, dried, weighed, and the weight recorded. The pycnometer shall be filled with distilled water (Note 3) essentially at room temperature. The weight of the pycnometer and water, W_a , shall be determined and recorded. A thermometer shall be inserted in the water and its temperature T_i determined to the nearest whole degree.

NOTE 3—Kerosine is a better wetting agent than water for most soils and may be used in place of distilled water for oven-dried samples.

6.2 From the weight W_a determined at the observed temperature T_i , a table of values of weights W_a shall be prepared for a series of temperatures that are likely to prevail when

weights W_b are determined later (Note 4). These values of W_a shall be calculated as follows:

$$W_a \text{ (at } T_x) = (\text{density of water at } T_i / \text{density of water at } T_i) \times (W_a \text{ (at } T_i) - W_p) + W_p$$

where:

W_a = weight of pycnometer and water, g,

W_p = weight of pycnometer, g,

T_i = observed temperature of water, °C, and

T_x = any other desired temperature, °C.

NOTE 4—This method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. Bringing the pycnometer and contents to some designated temperature when weights W_a and W_b are taken, requires considerable time. It is much more convenient to prepare a table of weights W_a for various temperatures likely to prevail when weights W_b are taken. It is important that weights W_a and W_b be based on water at the same temperature. Values for the relative density of water at temperatures from 18 to 30°C are given in Table 1.

7. Sampling

7.1 The soil to be used in specific gravity test may contain its natural moisture or be oven-dried. The weight of the test sample on an oven-dry basis shall be at least 25 g when the volumetric flask is to be used, and at least 10 g when the stoppered bottle is to be used.

7.2 *Samples Containing Natural Moisture*—When the sample contains its natural moisture, the weight of the soil, W_n , on an oven-dry basis shall be determined at the end of the test by evaporating the water in an oven maintained at 230 ± 9°F (110 ± 5°C) (Note 5). Samples of clay soils containing their natural moisture content shall be dispersed in distilled water before placing in the flask, using the dispersing equipment specified in Method D 422 (Note 6).

7.3 *Oven-Dried Samples*—When an oven-dried sample is to be used, the sample shall be dried for at least 12 h, or to constant weight, in an oven maintained at 230 ± 9°F (110 ± 5°C) (Note 5), cooled in a desiccator, and weighed upon removal from the desiccator. The sample shall then be soaked in distilled water for at least 12 h.

NOTE 5—Drying of certain soils at 110°C may bring about loss of moisture of composition or hydration, and in such cases drying shall be done, if desired, in reduced air pressure and at a lower temperature.

NOTE 6—The minimum volume of slurry that can be prepared by the dispersing equipment specified in Method D 422 is such that a 500-mL flask is needed as the pycnometer.

8. Procedure

8.1 Place the sample in the pycnometer, taking care not to lose any of the soil in case the weight of the sample has been determined. Add distilled water to fill the volumetric flask about three-fourths full or the stoppered bottle about half full.

8.2 Remove entrapped air by either of the following methods: (1) subject the contents to a partial vacuum (air pressure not exceeding 100 mm Hg) or (2) boil gently for at least 10 min while occasionally rolling the pycnometer to assist in the removal of the air. Subject the contents to reduced air pressure either by connecting the pycnometer directly to an aspirator or vacuum pump, or by use of a bell jar. Some soils boil violently when subjected to reduced air pressure. It will be necessary in those cases to reduce the air pressure at a slower rate or to use a larger flask. Cool samples that are heated to room temperature.

8.3 Fill the pycnometer with distilled water, clean the outside and dry with a clean, dry cloth. Determine the weight of the pycnometer and contents, W_b , and the temperature in degrees Celsius, T_x , of the contents as described in Section 6.

9. Calculation and Report

9.1 Calculate the specific gravity of the soil, based on water at a temperature T_x , as follows:

$$\text{Specific gravity, } T_x/T_x = W_a/[W_o + (W_a - W_b)]$$

where:

W_o = weight of sample of oven-dry soil, g.

W_a = weight of pycnometer filled with water at temperature T_x (Note 7), g.

W_b = weight of pycnometer filled with water and soil at temperature T_x , g, and

T_x = temperature of the contents of the pycnometer when weight W_b was determined, °C.

NOTE 7—This value shall be taken from the table of values of W_o , prepared in accordance with 6.2, for the temperature prevailing when weight W_b was taken.

9.2 Unless otherwise required, specific gravity values reported shall be based on water at 20°C.

The value based on water at 20°C shall be calculated from the value based on water at observed temperature T_x , as follows:

$$\text{Specific gravity, } T_x/20^\circ\text{C} = K \times \text{specific gravity at } T_x$$

where:

K = a number found by dividing the density of water at temperature T_x by the relative density of water at 20°C. Values for a range of temperatures are given in Table 1.

9.3 When it is desired to report the specific gravity value based on water at 4°C, the specific gravity value may be calculated by multiplying the specific gravity value at temperature T_x by the relative density of water at temperature T_x .

9.4 When any portion of the original sample of soil is eliminated in the preparation of the sample, the portion on which the test has been made shall be reported.

10. Precision and Bias

10.1 Criteria for judging the acceptability of specific gravity test results obtained by this method on material passing the No. 4 (4.75-mm) sieve are given as follows (Note 8):

Material and Type Index	Standard Deviation ^a	Acceptable Range of Two Results (percent of mean)
<i>Single-operator precision:</i>		
Cohesive soils	0.021	0.6
Noncohesive soils	"	1.0
<i>Multilaboratory precision:</i>		
Cohesive soils	0.056	0.16
Noncohesive soils	"	0.25

^a These numbers represent, respectively, the (1S) and (2S) limits as described in Practice C 670.

^b Criteria for assigning standard deviation values for noncohesive soils are not available at the present time.

NOTE 8—The figures given in Column 2 are standard deviations that have been found to be appropriate for the materials described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

TABLE 1 Relative Density of Water and Conversion Factor K For Various Temperatures

Temperature, °C	Relative Density of Water	Correction Factor K
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

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Appendix C
FIELD ACTIVITIES--SOIL BORING AND SAMPLING



Standard Practice for SOIL INVESTIGATION AND SAMPLING BY AUGER BORINGS¹

This standard is issued under the fixed designation D 1452; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers equipment and procedures for the use of earth augers in shallow geotechnical exploration. This practice does not apply to sectional continuous flight augers.

2. Significance and Use

2.1 Auger borings often provide the simplest method of soil investigation and sampling. They may be used for any purpose where disturbed samples can be used and are valuable in connection with ground water level determination and indication of changes in strata and advancement of hole for spoon and tube sampling. Equipment required is simple and readily available. Depths of auger investigations are, however, limited by ground water conditions, soil characteristics, and the equipment used.

3. Apparatus

3.1 Hand-Operated Augers.

3.1.1 *Helical Augers*—Small lightweight augers generally available in sizes from 1 through 3 in. (25.4 through 76.2 mm).

3.1.1.1 *Spiral-Type Auger*, consisting of a flat thin metal strip, machine twisted to a spiral configuration of uniform pitch; having at one end, a sharpened or hardened point, with a means of attaching a shaft or extension at the opposite end.

3.1.1.2 *Ship-Type Auger*—Similar to a carpenter's wood bit. It is generally forged from steel and machined to the desired size and configuration. It is normally provided with sharpened and hardened nibs at the point end and with an integral shaft extending through

its length for attachment of a handle or extension at the opposite end.

3.1.2 *Open Tubular Augers*, ranging in size from 1.5 through 8 in. (38.1 through 203.2 mm) and having the common characteristic of appearing essentially tubular when viewed from the digging end.

3.1.2.1 *Orchard-Barrel Type*, consisting essentially of a tube having cutting lips or nibs hardened and sharpened to penetrate the formation on one end and an adaptor fitting for an extension or handle on the opposite end.

3.1.2.2 *Open-Spiral Type*, consisting of a flat thin metal strip that has been helically wound around a circular mandrel to form a spiral in which the flat faces of the strip are parallel to the axis of the augered hole. The lower helix edges are hard-faced to improve wear characteristics. The opposite end is fitted with an adaptor for extension.

3.1.2.3 *Closed-Spiral Type*—Nearly identical to the open-spiral type except, the pitch of the helically wound spiral is much less than that of the open-spiral type.

3.1.3 *Post-Hole Augers*, generally 2 through 8 in. (50.8 through 203.2 mm), and having in common a means of blocking the escape of soil from the auger.

3.1.3.1 *Clam-Shell Type*, consisting of two

¹ This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D 18.02 on Sampling and Related Field Testing for Soil Investigations.

Current edition approved June 12, 1980. Published August 1980. Originally published as D 1452 - 57 T. Last previous edition D 1452 - 65 (1972).



3.4 *Accessory Equipment*—Labels, field log sheets, sample jars, sealing wax, sample bags, and other necessary tools and supplies.

4. Procedure

4.1 Make the auger boring by rotating and advancing the desired distance into the soil. Withdraw the auger from the hole and remove the soil for examination and test. Return the empty auger to the hole and repeat the procedure. Continue the sequence until the required depth is reached.

4.2 Casing is required in unstable soil in which the bore hole fails to stay open and especially when the boring is extended below the ground-water level. The inside diameter of the casing must be slightly larger than the diameter of the auger used. The casing shall be driven to a depth not greater than the top of the next sample and shall be cleaned out by means of the auger. The auger can then be inserted into the bore hole and turned below the bottom of the casing to obtain a sample.

4.3 The soil auger can be used both for boring the hole and for bringing up disturbed samples of the soil encountered. The structure of a cohesive soil is completely destroyed and the moisture may be changed by the auger. Seal all samples in a jar or other airtight container and label appropriately. If more than one type of soil is picked up in the sample, prepare a separate container for each type of soil.

4.4 *Field Observations*—Record complete ground water information in the field logs. Where casing is used, measure ground water levels, both before and after the casing is pulled. In sands, determine the water level at least 30 min after the boring is completed; in silts, at least 24 h. In clays, no accurate water level determination is possible unless pervious seams are present. As a precaution, however, water levels in clays shall be taken after at least 24 h.

5. Report

5.1 The data obtained in boring shall be recorded in the field logs and shall include the following:

- 5.1.1 Date of start and completion of boring.
- 5.1.2 Identifying number of boring.
- 5.1.3 Reference datum including direction

halves, hinged to allow opening and closing for alternately digging and retrieving. It is not usable deeper than about 3.5 ft (1.07 m).

3.1.3.2 *Iwan Type*, consisting of two tubular steel segments, connected at the top to a common member to form a nearly complete tube, but with diametrically opposed openings. It is connected at the bottom by two radial blades pushed to serve as cutters which also block the escape of contained soil. Attachment of handle or extension is at the top connector.

3.2 Machine-Operated Augers.

3.2.1 *Helical Augers*, generally 8 through 48 in. (203.2 through 1219 mm), consisting essentially of a center shaft fitted with a shank or socket for application of power, and having one or more complete 360° (6.28-rad) spirals for conveyance and storage of cut soil. Cutter bits and pilot bits are available in moderate and heavy-duty types and normally replaceable in the field. They are normally operated by heavy-duty, high-torque machines, designed for heavy construction work.

3.2.2 *Stinger Augers*, generally 6 through 30 in. (152.4 through 762 mm), are similar to the helical auger in 3.2.1, but lighter and generally smaller. They are commonly operated by light-duty machines for post and power pole holes.

3.2.3 *Disk Augers*, generally 10 through 30 in. (254 through 762 mm), consisting essentially of a flat, steel disk with diametrically opposed segments removed and having a shank or socket located centrally for application of power. Replaceable cutter bits, located downward from the leading edges of the remaining disk, dig and load soil that is held on the disk by valves or shutters hinged at the disk in order to close the removed segments. The disk auger is specifically designed to be operated by machines having limited vertical clearance between spindle and ground surface.

3.2.4 *Bucket Auger*, generally 12 through 48 in. (304.8 through 1219 mm), consisting essentially of a disk auger, without shank or socket, but hinge-mounted to the bottom of a steel tube or bucket of approximately the same diameter as the disk auger. A socket or shank for power application is located in the top center of the bucket diametral cross piece provided for the purpose.

3.3 *Casing* (when needed), consisting of pipe of slightly larger diameter than the auger used.



and distance of boring relative to reference line of project or other suitable reference points,

5.1.4 Type and size of auger used in boring,

5.1.5 Depth of changes in strata,

5.1.6 Description of soil in each major stratum,

5.1.7 Ground water elevation and location of seepage zones, when found, and

5.1.8 Condition of augered hole upon removal of auger, that is, whether the hole remains open or the sides cave, when such can be observed.

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Designation: D 1556 - 82¹

Standard Test Method for DENSITY OF SOIL IN PLACE BY THE SAND-CONE METHOD¹

This standard is issued under the fixed designation D 1556; the number immediately following the designation indicates the original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last revision. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

Section 7.5.3 was changed editorially in December 1983.

This method covers the determination of in-place density of soils.

Any soil or other material that can be tested with hand tools can be tested provided the void or pore openings in the mass are small enough to prevent the sand used in the test from entering the natural voids. The soil or other material being tested should have sufficient cohesion or particle attraction to maintain its sides on a small hole or excavation. It should also be firm enough to withstand the pressures exerted in digging the hole and holding the apparatus over it without deforming or sloughing.

When the moisture content and dry density are to be determined, this method is not to be used in certain soils or materials as indicated in paragraphs 1.3 and 3.5 of Method D 2216.

Applicable Documents

ASTM Standards:

D 136 Method for Sieve Analysis of Fine and Coarse Aggregates²

D 653 Terms and Symbols Relating to Soil and Rock³

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop³

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop³

D 2049 Test Method for Relative Density of Cohesionless Soils⁴

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures³

3. Significance and Use

3.1 This method is used widely to determine the density of compacted soils used in the construction of earth embankments, road fill, and structure backfill. It is often used as the basis of acceptance for soils compacted to a specified density or percentage of a maximum density determined by a standard test method.

3.2 This method can be used to determine in-place density of natural soil deposits, aggregates, soil mixtures, or other similar material.

3.3 The use of this method is generally limited to soil in an unsaturated condition. This method is not recommended for soils that are soft or friable (crumble easily) or in a moisture condition such that water seeps into the hand-excavated hole. The accuracy of the test may be affected for soils that deform easily or that may undergo a volume change in the excavated hole from standing or walking near the hole during the test.

4. Apparatus

4.1 *Density Apparatus*, consisting of the following:

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 04.08.

⁴ Discontinued, see 1983 Annual Book of ASTM Standards, Vol 04.08.



Standard Method for PENETRATION TEST AND SPLIT-BARREL SAMPLING OF SOILS¹

This standard is issued under the fixed designation D 1586; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specification and Standards.

1. Scope

1.1 This method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler to obtain a representative soil sample and a measure of the resistance of the soil to penetration of the sampler.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For a specific precautionary statement, see 5.4.1.*

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Applicable Documents

2.1 ASTM Standards:

- D 2487 Test Method for Classification of Soils for Engineering Purposes²
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)²
- D 4220 Practices for Preserving and Transporting Soil Samples²

3. Descriptions of Terms Specific to This Standard

3.1 *anvil*—that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drill rods.

3.2 *cathead*—the rotating drum or windlass in the rope-cathead lift system around which the operator wraps a rope to lift and drop the hammer

by successively tightening and loosening the rope turns around the drum.

3.3 *drill rods*—rods used to transmit downward force and torque to the drill bit while drilling a borehole.

3.4 *drive-weight assembly*—a device consisting of the hammer, hammer fall guide, the anvil, and any hammer drop system.

3.5 *hammer*—that portion of the drive-weight assembly consisting of the 140 ± 2 lb (63.5 ± 1 kg) impact weight which is successively lifted and dropped to provide the energy that accomplishes the sampling and penetration.

3.6 *hammer drop system*—that portion of the drive-weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow.

3.7 *hammer fall guide*—that part of the drive-weight assembly used to guide the fall of the hammer.

3.8 *N-value*—the blowcount representation of the penetration resistance of the soil. The N-value, reported in blows per foot, equals the sum of the number of blows required to drive the sampler over the depth interval of 6 to 18 in. (150 to 450 mm) (see 7.3).

3.9 ΔN —the number of blows obtained from each of the 6-in. (150-mm) intervals of sampler penetration (see 7.3).

3.10 *number of rope turns*—the total contact angle between the rope and the cathead at the

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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² Annual Book of ASTM Standards, Vol 04.08.



winning of the operator's rope slackening to top the hammer, divided by 360° (see Fig. 1).

3.11 *sampling rods*—rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.12 *SPT*—abbreviation for Standard Penetration Test, a term by which engineers commonly refer to this method.

Significance and Use

This method provides a soil sample for identification purposes and for laboratory tests appropriate for soil obtained from a sampler that produce large shear strain disturbance in the soil.

This method is used extensively in a great variety of geotechnical exploration projects. Local correlations and widely published relations which relate SPT blowcount, or *N*, and the engineering behavior of earths and foundations are available.

Apparatus

Drilling Equipment—Any drilling equipment that provides at the time of sampling a fairly clean open hole before insertion of the sampler and ensures that the penetration test is performed on undisturbed soil shall be acceptable. The following pieces of equipment have been found to be suitable for advancing a borehole in some subsurface conditions.

1. *Drag, Chopping, and Fishtail Bits*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjunction with open-hole rotary drilling or casing-advance drilling methods. To avoid disturbance of underlying soil, bottom discharge bits are not permitted; only side discharge bits are permitted.

2. *Roller-Cone Bits*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjunction with open-hole rotary drilling or casing-advance drilling methods if the drilling fluid discharge is deflected.

3. *Hollow-Stem Continuous Flight Augers*, with or without a center bit assembly, may be used to drill the boring. The inside diameter of hollow-stem augers shall be less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm).

4. *Solid, Continuous Flight, Bucket and Hand Augers*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used if the soil on the side of the boring does not

cave onto the sampler or sampling rods during sampling.

5.2 *Sampling Rods*—Flush-joint steel drill rods shall be used to connect the split-barrel sampler to the drive-weight assembly. The sampling rod shall have a stiffness (moment of inertia) equal to or greater than that of parallel wall "A" rod (a steel rod which has an outside diameter of 1½ in. (41.2 mm) and an inside diameter of 1½ in. (28.5 mm)).

NOTE 1—Recent research and comparative testing indicates the type rod used, with stiffness ranging from "A" size rod to "N" size rod, will usually have a negligible effect on the *N*-values to depths of at least 100 ft (30 m).

5.3 *Split-Barrel Sampler*—The sampler shall be constructed with the dimensions indicated in Fig. 2. The driving shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The use of liners to produce a constant inside diameter of 1½ in. (35 mm) is permitted, but shall be noted on the penetration record if used. The use of a sample retainer basket is permitted, and should also be noted on the penetration record if used.

NOTE 2—Both theory and available test data suggest that *N*-values may increase between 10 to 30 % when liners are used.

5.4 Drive-Weight Assembly:

5.4.1 *Hammer and Anvil*—The hammer shall weigh 140 ± 2 lb (63.5 ± 1 kg) and shall be a solid rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. A hammer fall guide permitting a free fall shall be used. Hammers used with the cathead and rope method shall have an unimpeded overlift capacity of at least 4 in. (100 mm). For safety reasons, the use of a hammer assembly with an internal anvil is encouraged.

NOTE 3—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2 *Hammer Drop System*—Rope-cathead, trip, semi-automatic, or automatic hammer drop systems may be used, providing the lifting apparatus will not cause penetration of the sampler while re-engaging and lifting the hammer.

5.5 *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, and groundwater level measuring devices shall be provided in accordance with the requirements of the project and other ASTM standards.

6. Drilling Procedure

6.1 The boring shall be advanced incrementally to permit intermittent or continuous sampling. Test intervals and locations are normally stipulated by the project engineer or geologist. Typically, the intervals selected are 5 ft (1.5 m) or less in homogeneous strata with test and sampling locations at every change of strata.

6.2 Any drilling procedure that provides a suitably clean and stable hole before insertion of the sampler and assures that the penetration test is performed on essentially undisturbed soil shall be acceptable. Each of the following procedures have proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used.

6.2.1 Open-hole rotary drilling method.

6.2.2 Continuous flight hollow-stem auger method.

6.2.3 Wash boring method.

6.2.4 Continuous flight solid auger method.

6.3 Several drilling methods produce unacceptable borings. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. The continuous flight solid auger method shall not be used for advancing the boring below a water table or below the upper confining bed of a confined non-cohesive stratum that is under artesian pressure. Casing may not be advanced below the sampling elevation prior to sampling. Advancing a boring with bottom discharge bits is not permissible. It is not permissible to advance the boring for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

6.4 The drilling fluid level within the boring or hollow-stem augers shall be maintained at or above the in situ groundwater level at all times during drilling, removal of drill rods, and sampling.

7. Sampling and Testing Procedure

7.1 After the boring has been advanced to the desired sampling elevation and excessive cuttings have been removed, prepare for the test with the following sequence of operations.

7.1.1 Attach the split-barrel sampler to the sampling rods and lower into the borehole. Do

not allow the sampler to drop onto the soil to be sampled.

7.1.2 Position the hammer above and attach the anvil to the top of the sampling rods. This may be done before the sampling rods and sampler are lowered into the borehole.

7.1.3 Rest the dead weight of the sampler, rods, anvil, and drive weight on the bottom of the boring and apply a seating blow. If excessive cuttings are encountered at the bottom of the boring, remove the sampler and sampling rods from the boring and remove the cuttings.

7.1.4 Mark the drill rods in three successive 6-in. (0.15-m) increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 6-in. (0.15-m) increment.

7.2 Drive the sampler with blows from the 140-lb (63.5-kg) hammer and count the number of blows applied in each 6-in. (0.15-m) increment until one of the following occurs:

7.2.1 A total of 50 blows have been applied during any one of the three 6-in. (0.15-m) increments described in 7.1.4.

7.2.2 A total of 100 blows have been applied.

7.2.3 There is no observed advance of the sampler during the application of 10 successive blows of the hammer.

7.2.4 The sampler is advanced the complete 18 in. (0.45 m) without the limiting blow counts occurring as described in 7.2.1, 7.2.2, or 7.2.3.

7.3 Record the number of blows required to effect each 6 in. (0.15 m) of penetration or fraction thereof. The first 6 in. is considered to be a seating drive. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance", or the "N-value". If the sampler is driven less than 18 in. (0.45 m), as permitted in 7.2.1, 7.2.2, or 7.2.3, the number of blows per each complete 6-in. (0.15-m) increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 1 in. (25 mm), in addition to the number of blows. If the sampler advances below the bottom of the boring under the static weight of the drill rods or the weight of the drill rods plus the static weight of the hammer, this information should be noted on the boring log.

7.4 The raising and dropping of the 140-lb

(63.5-kg) hammer shall be accomplished using either of the following two methods:

7.4.1 By using a trip, automatic, or semi-automatic hammer drop system which lifts the 140-lb (63.5-kg) hammer and allows it to drop 30 ± 0 in. (0.76 m ± 25 mm) unimpeded.

7.4.2 By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used the system and operation shall conform to the following:

7.4.2.1 The cathead shall be essentially free of dirt, oil, or grease and have a diameter in the range of 6 to 10 in. (150 to 250 mm).

7.4.2.2 The cathead should be operated at a minimum speed of rotation of 100 RPM, or the approximate speed of rotation shall be reported in the boring log.

7.4.2.3 No more than 2¼ rope turns on the cathead may be used during the performance of penetration test, as shown in Fig. 1.

NOTE 4—The operator should generally use either 2 or 2¼ rope turns, depending upon whether or not the rope comes off the top (1¼ turns) or the bottom (2 turns) of the cathead. It is generally known and accepted that 2¼ or more rope turns considerably impedes the fall of the hammer and should not be used to perform the test. The cathead rope should be maintained in a relatively dry, clean, and unfrayed condition.

7.4.2.4 For each hammer blow, a 30-in. (0.76-m) lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke.

7.5 Bring the sampler to the surface and open. Record the percent recovery or the length of sample recovered. Describe the soil samples recovered as to composition, color, stratification, and condition, then place one or more representative portions of the sample into sealable moisture-proof containers (jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of soil moisture. Affix labels to the containers bearing job designation, boring number, sample depth, and the blow count per 6-in. (0.15-m) increment. Protect the samples against extreme temperature changes. If there is a soil change within the sampler, make a jar for each stratum and note its location in the sampler barrel.

8. Report

8.1 Drilling information shall be recorded in the field and shall include the following:

- 8.1.1 Name and location of job,
- 8.1.2 Names of crew,
- 8.1.3 Type and make of drilling machine,
- 8.1.4 Weather conditions,
- 8.1.5 Date and time of start and finish of boring,
- 8.1.6 Boring number and location (station and coordinates, if available and applicable),
- 8.1.7 Surface elevation, if available,
- 8.1.8 Method of advancing and cleaning the boring,
- 8.1.9 Method of keeping boring open,
- 8.1.10 Depth of water surface and drilling depth at the time of a noted loss of drilling fluid, and time and date when reading or notation was made,
- 8.1.11 Location of strata changes,
- 8.1.12 Size of casing, depth of cased portion of boring,
- 8.1.13 Equipment and method of driving sampler,
- 8.1.14 Type sampler and length and inside diameter of barrel (note use of liners),
- 8.1.15 Size, type, and section length of the sampling rods, and
- 8.1.16 Remarks.

8.2 Data obtained for each sample shall be recorded in the field and shall include the following:

- 8.2.1 Sample depth and, if utilized, the sample number,
- 8.2.2 Description of soil,
- 8.2.3 Strata changes within sample,
- 8.2.4 Sampler penetration and recovery lengths, and
- 8.2.5 Number of blows per 6-in. (0.15-m) or partial increment.

9. Precision and Bias

9.1 Variations in N-values of 100 % or more have been observed when using different standard penetration test apparatus and drillers for adjacent borings in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, N-values in the same soil can be reproduced with a coefficient of variation of about 10 %.

9.2 The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low speed cathead, an old, oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in N-values

obtained between operator-drill rig systems.
9.3 The variability in N -values produced by different drill rigs and operators may be reduced by measuring that part of the hammer energy

delivered into the drill rods from the sampler and adjusting N on the basis of comparative energy. A method for energy measurement and N -value adjustment is currently under development.

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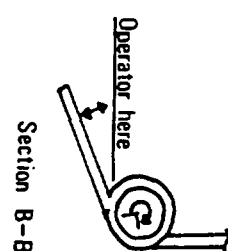
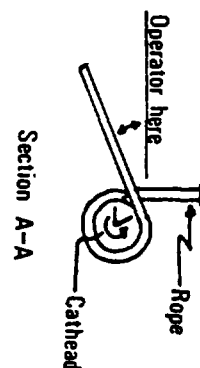
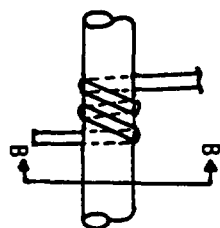
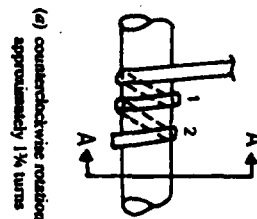
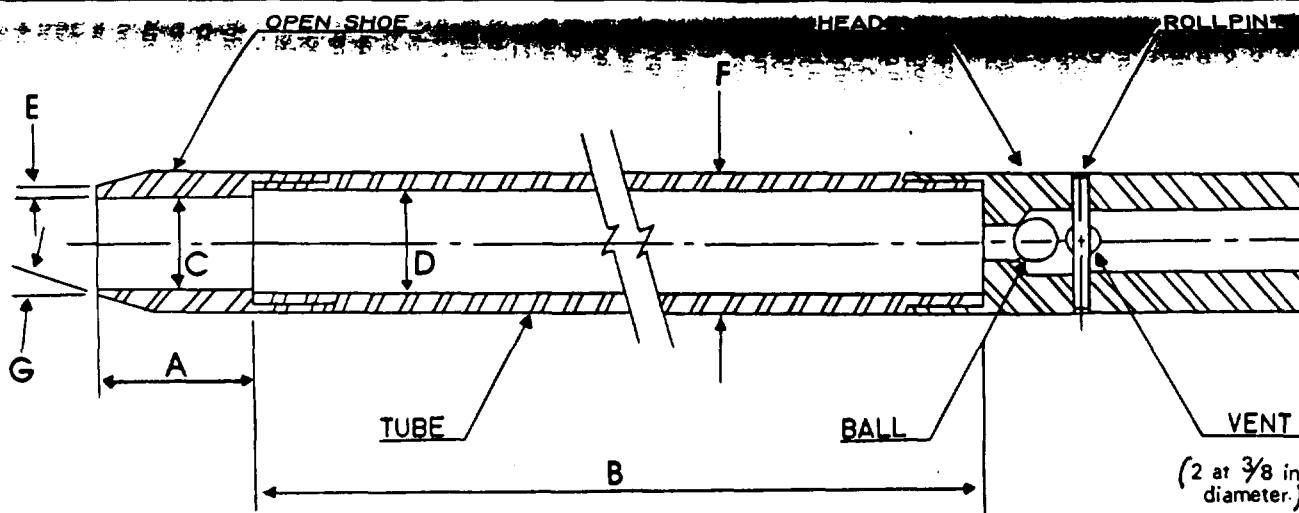


FIG. 1 Definitions of the Number of Rope Turns and the Angle for (a) Counterclockwise Rotation and (b) Clockwise Rotation of the Cathead



- A = 1.0 to 2.0 in. (25 to 50 mm)
- B = 18.0 to 30.0 in. (0.457 to 0.762 m)
- C = 1.375 ± 0.005 in. (34.93 ± 0.13 mm)
- D = $1.50 \pm 0.05 - 0.00$ in. ($38.1 \pm 1.3 - 0.0$ mm)
- E = 0.10 ± 0.02 in. (2.54 ± 0.25 mm)
- F = $2.00 \pm 0.05 - 0.00$ in. ($50.8 \pm 1.3 - 0.0$ mm)
- G = 16.0° to 23.0°

The $1\frac{1}{2}$ in. (38 mm) inside diameter split barrel may be used with a 16-gage wall thickness split liner. The penetrating end of the drive shoe may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

FIG. 2 Split-Barrel Sampler

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

Appendix D
FIELD SOIL TESTINGS

- Cone Pentrometer Sounding
- Field Density Test
- In Situ Density Test



Standard Test Method for DEEP, QUASI-STATIC, CONE AND FRICTION-CONE PENETRATION TESTS OF SOIL¹

This standard is issued under the fixed designation D 3441; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of end bearing and side friction, the components of penetration resistance which are developed during the steady slow penetration of a pointed rod into soil. This method is sometimes referred to as the "Dutch Cone Test," or "Cone Penetration Test" and is often abbreviated as the "CPT."

1.2 This test method includes the use of both cone and friction-cone penetrometers, of both the mechanical and electric types. It does not include data interpretation. It also includes the penetrometer aspects of piezocone soundings, but does not include the details of piezometer construction, location, measurement, or data interpretation.

NOTE 1—The European Standard for the CPT uses a tip of right cylindrical shape as shown in Fig. 3, as their reference test against which other CPTs may be compared.

1.3 Mechanical penetrometers of the type described in this method operate incrementally, using a telescoping penetrometer tip, resulting in no movement of the push rods during the measurement of the resistance components. Design constraints for mechanical penetrometers preclude a complete separation of the end-bearing and side-friction components. Electric penetrometers are advanced continuously and permit separate measurement of both components. Differences in shape and method of advance between cone penetrometer tips may result in significant differences in one or both resistance components.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility

of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Definitions

2.1 *cone*—the cone-shaped point of the penetrometer tip, upon which the end-bearing resistance develops.

2.2 *cone penetrometer*—an instrument in the form of a cylindrical rod with a conical point designed for penetrating soil and soft rock and for measuring the end-bearing component of penetration resistance.

2.3 *cone resistance or end-bearing resistance, q_c* —the resistance to penetration developed by the cone, equal to the vertical force applied to the cone divided by its horizontally projected area.

2.4 *cone sounding*—the entire series of penetration tests performed at one location when using a cone penetrometer.

2.5 *electric penetrometer*—a penetrometer that uses electric-force transducers built into a nonteleoperating penetrometer tip for measuring, within the tip, the component(s) of penetration resistance.

2.6 *friction-cone penetrometer*—a cone penetrometer with the additional capability of measuring the local side friction component of penetration resistance.

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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2.7 *friction-cone sounding*—the entire series of penetration tests performed at one location when using a friction-cone penetrometer.

2.8 *friction ratio, R_f* —the ratio of friction resistance to cone resistance, f_s/q_c , expressed in percent.

2.9 *friction resistance, f_s* —the resistance to penetration developed by the friction sleeve, equal to the vertical force applied to the sleeve divided by its surface area. This resistance consists of the sum of friction and adhesion.

2.10 *friction sleeve*—a section of the penetrometer tip upon which the local side-friction resistance develops.

2.11 *inner rods*—rods that slide inside the outer rods to extend the tip of a mechanical penetrometer.

2.12 *mechanical penetrometer*—a penetrometer that uses a set of inner rods to operate a telescoping penetrometer tip and to transmit the component(s) of penetration resistance to the surface for measurement.

2.13 *penetrometer tip*—the end section of the penetrometer, which comprises the active elements that sense the soil resistance, the cone, and the sleeve of the friction-cone penetrometer, the friction sleeve.

2.14 *Discussion*—The addition of a piezometer to the electric penetrometer tip permits the measurement of pore water pressure during and after stopping tip penetration. A penetrometer including a piezometer is known as a piezocone penetrometer, or just piezocone.

2.15 *piezocone sounding*—the entire series of penetration tests performed at one location when using a piezocone penetrometer.

2.16 *push rods*—the thick-walled tubes, or other suitable rods, used for advancing the penetrometer tip to the required test depth.

3. Significance and Use

3.1 This test method supplies data on the engineering properties of soil intended to help in the design and construction of earthworks and the foundations for structures.

3.2 This test method tests the soil in place and does not obtain soil samples. The interpretation of the results from this method requires knowledge of the types of soil penetrated. Engineers usually obtain this soil information from parallel borings and soil sampling methods, but prior information or experience may preclude the need

for borings.

3.3 Engineers often correlate the results of tests by this test method with laboratory or other types of field tests, or directly with performance. The accuracy of such correlations will vary with the type of soil involved. Engineers usually rely on local experience to judge this accuracy.

3.4 Most engineers with offshore experience have also found this test method suitable for offshore use.

4. Apparatus

4.1 General:

4.1.1 *Cone*—The cone shall have a $60^\circ (\pm 5^\circ)$ point angle and a base diameter of 1.406 ± 0.016 in. (35.7 ± 0.4 mm), resulting in a projected area of 1.55 in.^2 (10 cm^2). The point of the cone shall have a radius less than $1/8$ in. (3 mm).

NOTE 2—Cone tips with larger end areas may be used to increase measurement sensitivity in weak soils. Experience with electrical tips with end area between 0.78 in.^2 (5 cm^2) and 3.10 in.^2 (20 cm^2) has shown that they produce data similar to the 1.55 in.^2 (10 cm^2) standard provided they maintain the same tip geometry. Cone tip sizes in this range may be used for special circumstances provided the cone tip and friction sleeve (if any) area is noted.

4.1.2 *Friction Sleeve*, having the same outside diameter $+0.024$ to -0.000 in. ($+0.5$ to -0.0 mm) as the base diameter of the cone (see 4.1.1). No other part of the penetrometer tip shall project outside the sleeve diameter. The surface area of the sleeve shall be 23.2 in.^2 (150 cm^2) $\pm 2\%$.

4.1.3 *Steel*—The cone and friction sleeve shall be made from steel of a type and hardness suitable to resist wear due to abrasion by soil. The friction sleeve shall have and maintain with use a roughness of $20 \mu\text{in.}$ ($0.5 \mu\text{m}$) AA, $\pm 50\%$.

4.1.4 *Push Rods*—Made of suitable steel, these rods must have a section adequate to sustain, without buckling, the thrust required to advance the penetrometer tip. They must have an outside diameter not greater than the diameter of the base of the cone for a length of at least 1.3 ft (0.4 m) above the base, or, in the case of the friction-cone penetrometer, at least 1.0 ft (0.3 m) above the top of the friction sleeve. Each push rod must have the same, constant inside diameter. They must screw or attach together to bear against each other and form a rigid-jointed string of rods with a continuous, straight axis.

4.1.5 *Inner Rods*—Mechanical penetrometers require a separate set of steel, or other metal

alloy, inner rods within the steel push rods. The inner rods must have a constant outside diameter with a roughness, excluding waviness, less than 10 $\mu\text{in.}$ (0.25 μm) AA. They must have the same length as the push rods (± 0.004 in. or ± 0.1 mm) and a cross section adequate to transmit the cone resistance without buckling or other damage. Clearance between inner rods and push rods shall be between 0.020 and 0.040 in. (0.5 and 1.0 mm). See 6.8.1.

4.1.6 Measurement Accuracy—Maintain the thrust-measuring instrumentation to obtain thrust measurements within $\pm 5\%$ of the correct values.

NOTE 3—Special, and preferably redundant, instrumentation may be required in the offshore environment to assure this accuracy and the proper operation of all the remote systems involved.

4.2 Mechanical Penetrometers:

4.2.1 The sliding mechanism necessary in a mechanical penetrometer tip must allow a downward movement of the cone in relation to the push rods of at least 1.2 in. (30.5 mm).

NOTE 4—At certain combinations of depth and tip resistance(s), the elastic compression of the inner rods may exceed the downward stroke that the thrust machine can apply to the inner rods relative to the push rods. In this case, the tip will not extend and the thrust readings will rise elastically to the end of the machine stroke and then jump abruptly when the thrust machine makes contact with the push rods.

4.2.2 Mechanical penetrometer tip design shall include protection against soil entering the sliding mechanism and affecting the resistance component(s) (see 4.2.3 and Note 5).

4.2.3 Cone Penetrometer—Figure 1 shows the design and action of one mechanical cone penetrometer tip. A mantle of reduced diameter is attached above the cone to minimize possible soil contamination of the sliding mechanism.

NOTE 5—An unknown amount of side friction may develop along this mantle and be included in the cone resistance.

4.2.4 Friction-Cone Penetrometer—Figure 2 shows the design and action of one telescoping mechanical friction-cone penetrometer tip. The lower part of the tip, including a mantle to which the cone attaches, advances first until the flange engages the friction sleeve and then both advance.

NOTE 6—The shoulder at the lower end of the friction sleeve encounters end-bearing resistance. In sands as much as two thirds of the sleeve resistance may

consist of bearing on this shoulder. Ignore this effect in soft to medium clays.

4.2.5 Measuring Equipment—Measure the penetration resistance(s) at the surface by a suitable device such as a hydraulic or electric load cell or proving ring.

4.3 Electric Penetrometers:

4.3.1 Cone Penetrometer—Figure 3 shows one design for an electric-cone penetrometer tip. The cone resistance is measured by means of a force transducer attached to the cone. An electric cable or other suitable system transmits the transducer signals to a data recording system. Electric-cone penetrometers shall permit continuous advance and recording over each push rod-length interval.

4.3.2 Friction-Cone Penetrometer—The bottom of the friction sleeve shall not be more than 0.4 in. (10 mm) above the base of the cone. The same requirements as 4.3.1 apply. Figure 4 shows one design for an electric friction-cone penetrometer tip.

4.3.3 Other Penetrometers—Electric penetrometers may include other transducer measurements as well as, or instead of, the friction sleeve measurement. Common ones are inclinometers to assist with the alignment control of the tip (see 6.3) and piezometers to provide additional data on soil stratigraphy and behavior.

4.4 Thrust Machine—This machine shall provide a continuous stroke, preferably over a distance greater than one push rod length. The machine must advance the penetrometer tip at a constant rate while the magnitude of the thrust required fluctuates (see 5.1.2).

NOTE 7—Deep penetration soundings usually require a thrust capability of at least 5 tons (45 kN). Most modern machines use hydraulic pistons with 10 to 20-ton (90 to 180-kN) thrust capability.

4.5 Reaction Equipment—The proper performance of the static-thrust machine requires a stable, static reaction.

NOTE 8—The type of reaction provided may affect the penetrometer resistance(s) measured, particularly in the surface or near-surface layers.

5. Procedure

5.1 General:

5.1.1 Set up the thrust machine for a thrust direction as near vertical as practical.

5.1.2 Rate of Penetration—Maintain a rate of depth penetration of 2 to 4 ft/min (10 to 20 mm

when obtaining resistance data. Other penetration may be used between tests.

NOTE 9—The rate of 2 ft/min (10 mm/s) provides the operator needs to read properly the resistances when using the mechanical friction-cone meter. The rate of 4 ft/min (20 mm/s) is suitable for single resistance reading required when using a mechanical cone penetrometer and provides for the operation of electric penetrometers. The standard requires 4 ft/min (20 mm/s).

NOTE 10—Rates of penetration either slower or faster than the standard rate may be used for special purposes, such as pore pressure measurements, provided the rate actually used and the deviation is noted on the test record.

NOTE 11—Pore pressures generated ahead of and within the penetrating cone or friction cone penetrometer have an important effect on the q_c and f_c measured. Piezocone tips with simultaneous pore measurement capability have proven useful to evaluate such effects and to provide additional data about the stratigraphy and engineering properties of soils penetrated.

Mechanical Penetrometers:

Cone Penetrometer—(1) Advance penetrometer tip to the required test depth by applying sufficient thrust on the push rods; and (2) obtain sufficient thrust on the inner rods to extend the penetrometer tip (see Fig. 1). Obtain the cone resistance at a specific point (see 5.2.3) during the downward movement of the inner rods relative to the stationary push rods. Repeat the test. (2) Apply sufficient thrust on the push rods to extend the tip and advance it to the required depth. By continually repeating this two-step process, obtain cone resistance data at increments of depth. This increment shall not ordinarily exceed 8 in. (203 mm).

Friction-Cone Penetrometer—Use this penetrometer as described in 5.2.1 but obtain both resistances during the step (2) extension of the tip (see Figs. 2 and 5). First obtain the cone resistance during the initial phase of the extension. When the lower part of the tip engages and penetrates down the friction sleeve, obtain a second measurement of the total resistance of the cone and the sleeve. Subtraction gives the sleeve resistance.

NOTE 12—Because of soil layering, the cone resistance may change during the additional downward movement of the tip required to obtain the friction resistance.

NOTE 13—The soil friction along the sleeve puts an additional overburden load on the soil above the cone and may increase cone resistance above that measured during the initial phase of the tip extension by an

unknown, but probably small amount. Ignore this effect.

5.2.3 Recording Data—To obtain reproducible cone-resistance test data, or cone and friction-resistance test data when using a friction-cone tip, record only those thrust readings that occur at a well-defined point during the downward movement of the top of the inner rods in relation to the top of the push rods. Because of the elastic compression of inner rods (see Note 4), this point ordinarily should be at not less than 1.0 in. (25 mm) apparent relative movement of the inner rods. When using the friction-cone penetrometer, this point shall be just before the cone engages the friction sleeve.

NOTE 14—Figure 5 shows one example of how the thrust in the hydraulic load cell can vary during the extension of the friction-cone tip. Note the jump in gage pressure when the cone engages the sleeve.

5.2.3.1 Obtain the cone plus friction-resistance reading as soon as possible after the jump so as to minimize the error described in Fig. 5. Unless using continuous recording as in Fig. 5, the operator should not record a cone plus friction resistance if he suspects the cone resistance is changing abruptly or erratically.

5.3 Electric Penetrometers:

5.3.1 If using continuous electric cable, pre-thread it through the push rods.

5.3.2 Record the initial reading(s) with the penetrometer tip hanging freely in air or in water, out of direct sunlight, and after an initial, short penetration, test hole so that the tip temperature is at soil temperature.

5.3.3 Record the cone resistance, or cone resistance and friction resistance, continuously with depth or note them at intervals of depth not exceeding 8 in. (203 mm).

5.3.4 At the end of a sounding, obtain a final set of readings as in 5.3.2 and check them against the initial set. Discard the sounding, and repair or replace the tip if this check is not satisfactory for the accuracy desired for the resistance component(s).

6. Special Techniques and Precautions

6.1 Reduction of Friction Along Push Rods—The purpose of this friction reduction is to increase the penetrometer depth capability, and not to reduce any differences between resistance components determined by mechanical and electric tips as noted in 1.3. To accomplish the

friction reduction, introduce a special rod with an enlarged diameter or special projections, called a "friction reducer," into the string of push rods or between the push rods and the tip. Another allowable method to reduce friction is to use push rods with a diameter less than that of the tip. In accordance with 4.1.4, any such projections or changes in diameter must begin no closer than 1.0 ft (0.3 m) from the base of the cone or the top of the friction sleeve when using cones with the standard 4.1.1 diameter. For other cones (see Note 2) use no closer than 8 diameters.

NOTE 15—Non-mechanical techniques to reduce friction, such as the use of drilling mud above the tip, are also allowable.

6.2 Prevention of Rod Bending Above Surface—Use a tubular rod guide, at the base of the thrust machine, of sufficient length to prevent significant bending of the push rods between the machine and the ground surface.

NOTE 16—Special situations, such as when working through water, will require a special system of casing support to restrict adequately the buckling of the push rods.

6.3 Drift of Tip—For penetration depths exceeding about 40 ft (12 m), the tip will probably drift away from a vertical alignment. Occasionally, serious drifting occurs, even at less depth. Reduce drifting by using push rods that are initially straight and by making sure that the initial cone penetration into soil does not involve unwanted, initial lateral thrust. Passing through or alongside an obstruction such as boulders, soil concretions, thin rock layers, or inclined dense layers may deflect the tip and induce drifting. Note any indications of encountering such obstructions and be alert for possible subsequent improper tip operation as a sign of serious drifting.

NOTE 17—Electric penetrometer tips may also incorporate an inclinometer to monitor drift and provide a warning when it becomes excessive.

6.4 Wear of Tip—Penetration into abrasive soils eventually wears down or scours the penetrometer tip. Discard tips, or parts thereof, whose wear changes their geometry or surface roughness so they no longer meet the requirements of 4.1. Permit minor scratches.

6.5 Distance Between Cone and Friction Sleeve—The friction resistance of the sleeve applies to the soil at some distance above the soil in which the cone resistance was obtained at the

same time. When comparing these resistances for the soil at a specified depth, for example when computing friction ratios or when plotting these data on graphs, take proper account of the vertical distance between the base of the cone and the midheight of the friction sleeve.

6.6 Interruptions—The engineer may have to interrupt the normal advance of a static penetration test for purposes such as removing the penetrometer and drilling through layers or obstructions too strong to penetrate statically. If the penetrometer is designed to be driven dynamically without damage to its subsequent static performance (those illustrated herein in Figs. 1 to 4 are not so designed), the engineer may drive past such layers or obstructions. Delays of over 10 min due to personnel or equipment problems shall be considered an interruption. Continuing the static penetration test after an interruption is permitted provided this additional testing remains in conformance with this standard. Obtain further resistance component data only after the tip passes through the engineer's estimate of the disturbed zone resulting from the nature and depth of the interruption. As an alternative, readings may be continued without first making the additional tip penetration and the disturbed zone evaluated from these data. Then disregard data within the disturbed zone.

NOTE 18—Interruption of the piezocone sounding after a push allows the engineer to examine the dissipation of positive or negative excess pore water pressure.

6.7 Below or Adjacent to Borings—A cone or friction-cone sounding shall not be performed any closer than 25 boring diameters from an existing, unbackfilled, uncased boring hole. When performed at the bottom of a boring, the engineer should estimate the depth below the boring of the disturbed zone and disregard penetration test data in this zone. The depth may vary from one to five diameters. Where the engineer does not have sufficient experience with this variable a depth of at least three boring diameters should be used.

6.8 Mechanical Penetrometers:

6.8.1 Inner Rod Friction—Soil particles and corrosion can increase the friction between inner rods and push rods, possibly resulting in significant errors in the measurement of the resistance component(s). Clean and lubricate the inner rods.

6.8.2 Weight of Inner Rods—For improved accuracy at low values of cone resistance, correct thrust data to include the accumulated weight of inner rods from the tip to the topmost rod.

6.8.3 Jamming—Soil particles between sliding surfaces or bending of the tip may jam the mechanism during the many extensions and retractions of the telescoping mechanical tip. Stop the sounding as soon as uncorrectable jamming occurs.

Electric Penetrometers:

7.1 Water Seal—Provide adequate water-tightness for the electric transducer. Make periodic checks to assure that no water has passed into the cone.

NOTE 19—Some electric tip sleeve designs are not compensated for hydrostatic end area effects and require calibration correction. Determining the net end area of the cone under hydrostatic pressure also requires hydrostatic calibration measurement. The tip manufacturer can usually supply these calibration correction factors. Their importance increases as the soil being tested becomes weaker.

Report

7.1 Graph of Cone Resistance, q_c —Every report of a cone or friction-cone sounding shall include a graph of the variation of cone resistance (in units of tons or kPa) with depth (in feet or meters). Successive cone-resistance test values from the mechanical cone and friction-cone penetrometers, usually determined at equal increments of depth and plotted at the depth corresponding to the depth of the measurement, may be connected with straight lines as an approximation for a continuous graph.

7.2 Friction-Cone Penetrometer:

7.2.1 Graph of Friction Resistance, f_s —In addition to the graph of cone resistance (7.1) the report may include an adjacent or superposed graph of friction resistance or friction ratio, or both, with depth. Use the same depth scale as in 7.1 (see 6.5).

7.2.2 Graph of Friction Ratio, R_f —If the report includes soil descriptions estimated from the friction-cone penetrometer data, include a graph

of the variation of friction ratio with depth. Place this graph adjacent to the graph for cone resistance, using the same depth scale (see 6.5).

7.3 Piezocone Penetrometer—In addition to the 7.1 and 7.2 report requirements, a piezocone sounding shall include a parallel graph, to the same depth scale, of measured pore water pressure during the penetration versus depth. Excess pore water pressure versus time plots may also be constructed at those depths where the piezocone sounding is interrupted (see Note 1).

7.4 General—The operator shall record his name, the name and location of the job, date of sounding, sounding number, location coordinates, and soil and water surface elevations (if available). The report shall also include a note as to the type of penetrometer tip used, the type of thrust machine, tip and thrust calibration information, or both, any zero-drift noted, the method used to provide the reaction force, if a friction reducer was used, the method of tip advancement, the method of recording, the condition of the rods and tip after withdrawal, and any special difficulties or other observations concerning the performance of the equipment.

7.5 Deviations from Standard—The report shall state that the test procedures were in accordance with this Test Method D 3441. Describe completely any deviations from this test method.

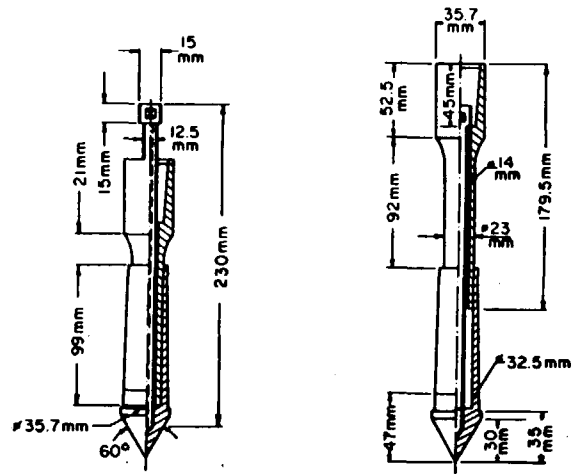
8. Precision and Bias

8.1 Because of the many variables involved and the lack of a superior standard, engineers have no direct data to determine the bias of this method. Judging from its observed reproducibility in approximately uniform soil deposits, plus the q_c and f_s measurement effects of special equipment and operator care, persons familiar with this method estimate its precision as follows:

8.1.1 Mechanical Tips—Standard deviation of 10 % in q_c and 20 % in f_s .

8.1.2 Electric Tips—Standard deviation of 5 % in q_c and 10 % in f_s .

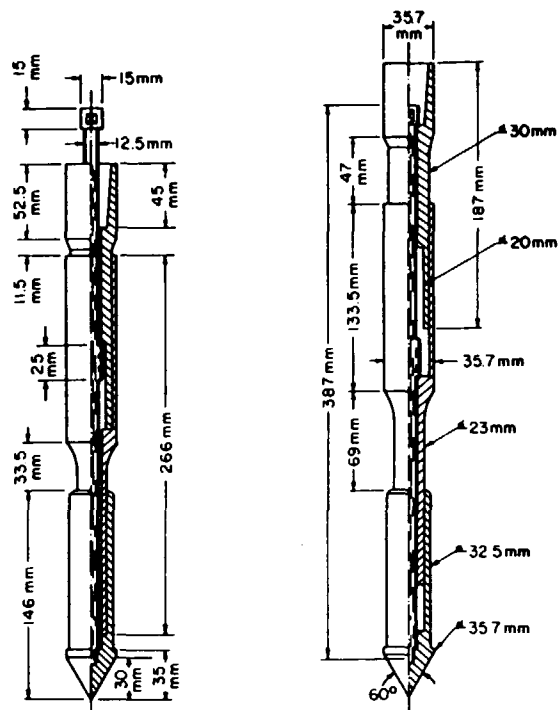
NOTE 20—These data may not match similar data from mechanical tips (see 1.3).



COLLAPSED

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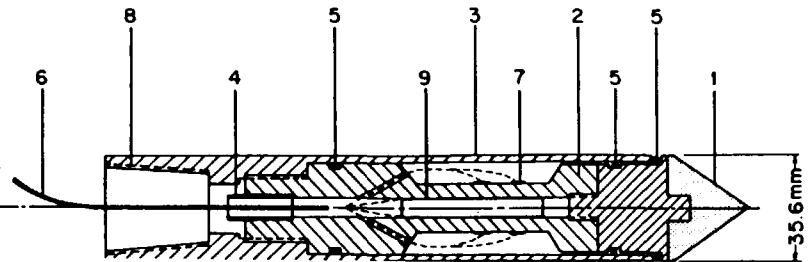
FIG. 1 Example of a Mechanical Cone Penetrometer Tip (Dutch Mantle Cone)



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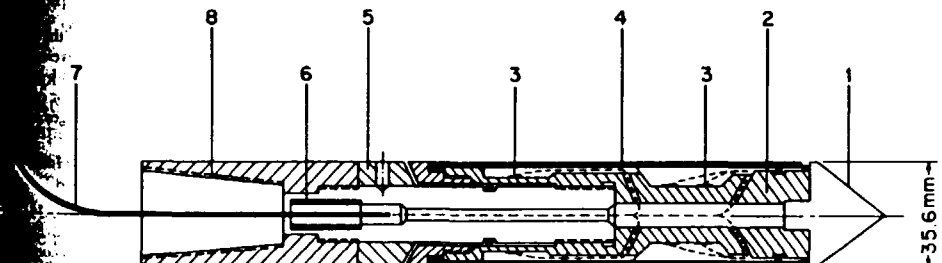
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FIG. 2 Example of a Mechanical Friction-Cone Penetrometer Tip (Begemann Friction-Cone)



- 1 Conical point (10 cm²)
- 2 Load cell
- 3 Protective mantle
- 4 Waterproof bushing
- 5 O-rings
- 6 Cable
- 7 Strain gages
- 8 Connection with rods
- 9 Inclinometer

FIG. 3 Electric-Cone Penetrometer Tip

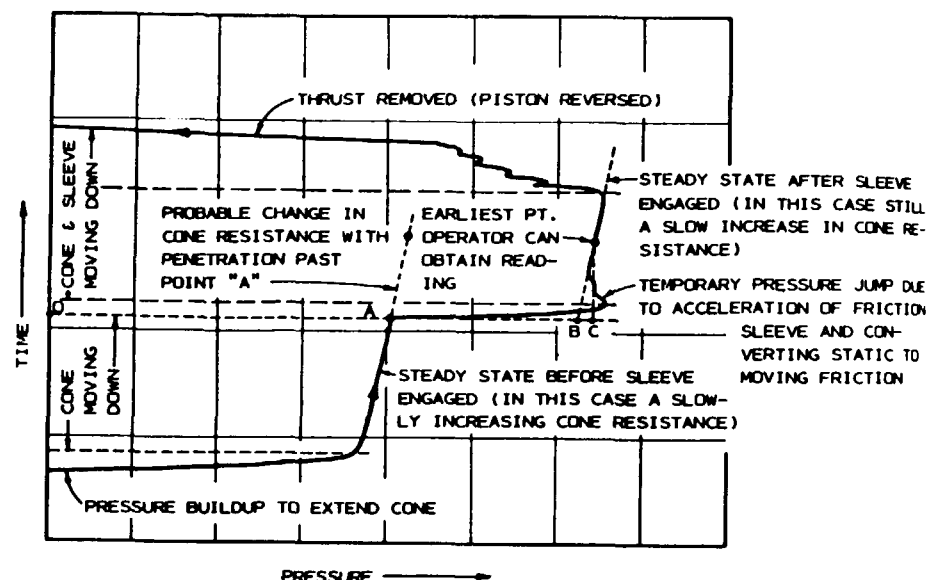


- 1 Conical point (10 cm²)
- 2 Load cell
- 3 Strain gages
- 4 Friction sleeve (150 cm²)
- 5 Adjustment ring
- 6 Waterproof bushing
- 7 Cable
- 8 Connection with rods

FIG. 4 Electric Friction-Cone Penetrometer Tip

Standard Practice for RING-LINED BARREL SAMPLING OF SOILS¹

This standard is issued under the fixed designation D 3550; the number immediately following the designation indicates the year of adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. An epsilon (ϵ) indicates an editorial change since the last revision or reapproval.



NOTE—"o-a" represents the correct cone resistance reading just before the pressure jump associated with engaging the friction sleeve during the continuing downward extension of the tip. "a-b" is the correct friction resistance if the friction sleeve could be engaged instantaneously and the cone plus friction resistance read instantaneously. However, the operator cannot read a pressure gage dial until it steadies, such as at point "c." By this forced wait, the operator has introduced a friction resistance error of "bc." The operator must read the gage as soon as possible after the jump to minimize this error. Erratic or abrupt changes in cone resistance may make this error unacceptable.

FIG. 5 Annotated Chart Record of the Pressure Changes in the Hydraulic Load Cell Measuring Thrust on Top of the Inner Rod During an Example Extension of the Mechanical Friction-Cone Penetrometer Tip

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

cation of Soils (Visual-Manual Procedure)²

3. Significance and Use

3.1 This practice is used where soil condition and resistance to advance of the sampler do not permit the use of a thin-wall tube (Practice D 1587) and where the formation does not require diamond coring (Practice D 2113).

4. Apparatus

4.1 *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole before insertion of the sampler and that does not disturb the soil to be sampled. However, in no case shall a bottom-discharge bit be permitted. Side-discharge bits are permissible.

4.2 *Drive Weight Assembly*—Any drive weight assembly that will provide penetration in the range from 1 to 20 blows per foot (65 blows per metre) may be used. Whenever possible, soils are to be sampled by pushing instead of driving (see Section 5).

4.3 *Ring-Lined Barrel Sampling Assembly*—This shall consist of a shoe, sampler, and waste barrel, as shown in Fig. 1.

4.4 *Ring-Lined Sampler*—Test specimens shall be obtained using a suitable one piece or split sampling barrel lined on the inside with removable rings. These rings shall be thin-walled and shall conform to the size requirements of the particular laboratory test determinations employed. They shall fit snugly inside the sampler

¹ This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

Current edition approved Jan. 27, 1984. Published April 1984. Originally published as D 3550 - 77. Last previous edition D 3550 - 77¹.

² Annual Book of ASTM Standards, Vol 04.08.

2. Applicable Documents

2.1 ASTM Standards:

D 1586 Method for Penetration Test and Split-

Barrel Sampling of Soils²

D 1587 Practice for Thin-Walled Sampling of Soils²

D 2113 Practice for Diamond Core Drilling for Site Investigation²

D 2488 Practice for Description and Identifi-



Standard Test Method for DENSITY OF SOIL IN PLACE BY THE SAND-CONE METHOD¹

This standard is issued under the fixed designation D 1556; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

NOTE—Section 7.5.3 was changed editorially in December 1983.

1. Scope

1.1 This method covers the determination of the in-place density of soils.

1.2 Any soil or other material that can be excavated with hand tools can be tested provided the void or pore openings in the mass are small enough to prevent the sand used in the test from entering the natural voids. The soil or other material being tested should have sufficient cohesion or particle attraction to maintain stable sides on a small hole or excavation. It should also be firm enough to withstand the minor pressures exerted in digging the hole and placing the apparatus over it without deforming or sloughing.

1.3 When the moisture content and dry density are to be determined, this method is not to be used in certain soils or materials as indicated in paragraphs 1.3 and 3.5 of Method D 2216.

2. Applicable Documents

2.1 ASTM Standards:

C 136 Method for Sieve Analysis of Fine and Coarse Aggregates²

D 653 Terms and Symbols Relating to Soil and Rock³

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop³

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop³

D 2049 Test Method for Relative Density of Cohesionless Soils⁴

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures³

3. Significance and Use

3.1 This method is used widely to determine the density of compacted soils used in the construction of earth embankments, road fill, and structure backfill. It is often used as the basis of acceptance for soils compacted to a specified density or percentage of a maximum density determined by a standard test method.

3.2 This method can be used to determine in-place density of natural soil deposits, aggregates, soil mixtures, or other similar material.

3.3 The use of this method is generally limited to soil in an unsaturated condition. This method is not recommended for soils that are soft or friable (crumble easily) or in a moisture condition such that water seeps into the hand-excavated hole. The accuracy of the test may be affected for soils that deform easily or that may undergo a volume change in the excavated hole from standing or walking near the hole during the test.

4. Apparatus

4.1 *Density Apparatus*, consisting of the following:

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

Current edition approved Nov. 26, 1982. Published January 1983. Originally published as D 1556 - 58 T. Last previous edition D 1556 - 64 (1974).

² *Annual Book of ASTM Standards*, Vol 04.02.

³ *Annual Book of ASTM Standards*, Vol 04.08.

⁴ Discontinued, see 1983 *Annual Book of ASTM Standards*, Vol 04.08.

4.1.1 A jar or other container having a volume of approximately 1 gal (4000 cm³) or larger.

4.1.2 A detachable appliance consisting of a cylindrical valve with an orifice approximately ½ in. (13 mm) in diameter, having a small metal funnel connecting to a standard gal Mason jar top on one end and a large metal funnel (cone) on the other end. The valve shall have stops to prevent rotating it past the completely open or completely closed positions.

4.1.3 A square or rectangular metal plate with a flanged center hole cast or machined to receive the large funnel (cone) of the appliance described in 4.1.2. The plate shall be flat on the bottom and have sufficient thickness or stiffness to be rigid and shall have sidewalls approximately ¾ to ½ in. (10 to 13 mm) high.

4.1.4 The details for the apparatus described herein are shown in Fig. 1 and represent the minimum acceptable dimensions suitable for testing soils having maximum particle sizes of approximately 2 in. (50 mm) and test hole volumes of approximately 0.1 ft³ (3000 cm³). When the material being tested contains a small amount of oversize and isolated large particles are encountered, the test can be moved to a new location. Larger apparatus and test hole volumes are needed when particles larger than 2 in. (50 mm) are prevalent.

NOTE 1—The apparatus described here represents a design that has proved satisfactory. Larger apparatus of similar proportions may be used as long as the basic principles of the sand volume determination are observed.

4.2 Sand, shall be clean, dry, uniform, uncemented, durable, and free-flowing. Any gradation may be used that has a uniformity coefficient ($C_u = D_{60}/D_{10}$) less than 2.0, a maximum particle size less than 2.00 mm (No. 10 sieve), and less than 3 % by weight passing 250 µm (No. 60 sieve). The particle size distribution (gradation) shall be determined in accordance with Method C 136. Uniform sand is needed to prevent segregation during handling, storage, and use. Sand free of fines and fine sand particles is needed to prevent significant bulk density changes with normal daily changes in atmospheric humidity. Sand comprised of durable, natural subrounded or rounded particles is desirable. Crushed sand or sand having angular particles may not be free flowing, a condition that can cause bridging resulting in inaccurate

density determinations (Note 2). In selecting sand from a potential source, five separate bulk-density determinations shall be made on each container or bag of sand. To be acceptable sand, the variation between any determination and the average shall not be greater than 1 % of the average. Before using sand for density determinations, it shall be dried and allowed to reach an air-dried state in the original location where it is to be used. Sand not be reused without removing any contaminating soil, checking the gradation, and drying. Bulk-density tests shall be made at intervals not exceeding 14 days, always after any significant changes in atmospheric humidity, before reusing, and before using a new batch from a previously approved supplier (Note 3).

NOTE 2—Some manufactured (crushed) sands such as blasting sand have been successfully used with good reproducibility. The reproducibility of the results using angular sand should be checked in actual testing situations before selecting an angular sand for use.

NOTE 3—Most sands have a tendency to absorb moisture from the atmosphere. A very small amount of absorbed moisture can make a substantial change in bulk density. In areas of high humidity or where the humidity changes often, the bulk density may need to be determined more often than the 14-day maximum interval indicated. The need for frequent checks can be determined by comparing the results of different bulk-density tests on the same sand made in the area and conditions of use over a period of time.

4.3 Balances—A balance or scale of 10-lb capacity readable to 1.0 g and accurate to ±0.1 g from 100 g to 7000 g and 3 g above 7000 g, and a balance of 2000 g capacity readable to 0.1 g and accurate to 0.1 %.

4.4 Drying Equipment—Oven, as specified in Method D 2216 (See 6.1.10 and Note 6.)

4.5 Miscellaneous Equipment—Knife, small pick, chisel, small trowel, screwdriver, or spoons for digging test hole; buckets with lids; seamless tin or aluminum cans with lids, plastic-lined cloth sacks, or other suitable containers for retaining the density sample, moisture sample, and density sand respectively; thermometer for determining the temperature of water; small, paint-type brush, slide rule or calculator, notebook, etc.

5. Calibration

5.1 Determinations of mass are to be made to the nearest 1 g except for those required for

determining moisture content, which shall be made to the nearest 0.1 g.

5.2 Determine the mass of sand required to fill the funnel and base plate as follows:

5.2.1 Put sand in the apparatus and determine the mass of apparatus and sand.

5.2.2 Place the base plate on a clean, level, plane surface. Invert the apparatus and seat the large funnel into the flanged center hole in the base plate, and mark and identify the funnel and plate so that the same funnel and plate can always be matched and resealed in the same position.

5.2.3 Open the valve and keep open until the sand stops running, making sure the apparatus, base plate, or plane surface are not jarred or vibrated before the valve is closed.

5.2.4 Close the valve sharply, determine the mass of the apparatus with remaining sand and calculate the loss of sand. This loss represents the mass of sand required to fill the funnel and base plate.

5.2.5 Repeat the procedures in 5.2.1 to 5.2.4 at least three times. The mass of sand used in the calculations shall be the average of three determinations. The maximum variation between any one determination and the average shall not exceed 1 %.

5.3 Use either Method A or Method B to determine the sand bulk density.

5.4 Method A—Determine the bulk density of the sand to be used in the field test as follows:

5.4.1 Select a known-volume container that is approximately the same size and allows the sand to fall approximately the same distance as the hole excavated in making a field test. The 1-ft³ (944-cm³) and ½-ft³ (2124-cm³) molds specified in Test Methods D 698 or the 0.1-ft³ (2830-cm³) mold specified in Test Method D 2049 are recommended.

5.4.2 Make measurements of sufficient accuracy to determine the volume of the container to ±1.0 %. The measurement tolerances for the above recommended molds are given in Test Methods D 698 and D 2049.

5.4.3 Flow characteristics through different valve assemblies have been known to cause different bulk-density values. The funnel and valve apparatus used to determine the bulk density of the sand shall be the same as used for making field tests unless other assemblies are determined to provide the same results.

5.4.4 Fill the assembled apparatus with sand.

5.4.5 Determine the mass of the known-volume container when empty.

5.4.6 Support the apparatus over the known-volume container in an inverted position so that the sand falls approximately the same distance as in a field test, and fully open the valve.

5.4.7 Fill the container until it just overflows and close the valve. Carefully strike off excess sand to a smooth level surface at the top of the container. Care must be taken so that the container is not jarred or vibrated before striking off is completed.

5.4.8 Clean any sand from the outside of the container and determine the mass of the known-volume container when full. Determine the net mass of sand by subtracting the mass of the empty container.

NOTE 4—When the known-volume container has the same diameter as the flanged center hole in the metal plate, the procedures in 5.4.6 to 5.4.8 can be simplified by using the plate on top of the known-volume container. Striking off the excess sand is not required when the apparatus with sand is weighed before and after filling the container and the mass required to fill the cone and plate (5.2.5) is subtracted from the difference.

5.4.9 Repeat the procedure in 5.4.4 to 5.4.8 at least three times. The mass used in the calculations shall be the average of three determinations. The maximum variation between any one determination and the average shall not exceed 1 %.

5.5 Method B—The bulk density of sand to be used in the field test is determined by first determining the volume of the jar and attachment up to and including the volume of the valve orifice then by using the jar to measure a volume and mass of sand as follows:

5.5.1 In making bulk density determinations, use a glass or other rigid jar that is well-rounded where it tapers toward the opening. Other jars may be used for making in-place density tests.

5.5.2 Use the same funnel and valve assembly for determining the bulk density of sand as will be used in field tests or determine that other assemblies provide the same results.

5.5.3 Use heavy grease or other waterproof substances in those stopcocks and thread assemblies that are not watertight.

5.5.4 Determine the mass of the assembled apparatus and record.

5.5.5 Place the apparatus upright and open the valve.

5.5.6 Fill the apparatus with water until it appears over the valve.

5.5.7 Close valve and remove excess water.

5.5.8 Determine the mass of the apparatus and water, and determine the temperature of the water to the nearest 1°C.

5.5.9 To determine the mass of the water to fill the apparatus, subtract the mass of the apparatus from the mass of the apparatus and the water.

5.5.10 Repeat the procedure described in 5.5.4 to 5.5.9 at least three times. Convert the weight of water, in grams, to millilitres by correcting for the temperature as given in 7.3.1. The volume used shall be the average of three determinations with a maximum variation of 3 mL.

5.5.11 The volume determined in this procedure is constant as long as the jar and attachment are in the same relative position as the previous volume determination. If the two are to be separated, match marks should be made to permit reassembly to this position.

5.5.12 Completely dry the jar and other apparatus and remove any grease or waterproofing substances before proceeding with the following bulk density determination.

5.5.13 Place the empty apparatus upright on a firm level surface, close the valve, and fill the funnel with sand.

5.5.14 Open the valve and, keeping the funnel at least half full of sand, fill the apparatus, making sure the apparatus is not jarred or vibrated before the valve is closed. When the sand stops flowing, close the valve sharply and empty excess sand.

5.5.15 Determine the mass of the apparatus with sand and determine the net mass of sand by subtracting the mass of the apparatus.

5.5.16 Repeat the procedures in 5.5.13 to 5.5.15 at least three times. The mass used in the calculations shall be the average of three determinations. The maximum variation between any one determination and the average shall not exceed 1 %.

6. Procedure

6.1 Determine the density of the soil in place as follows:

6.1.1 Fill the apparatus with sand previously calibrated for bulk density and determine mass of the apparatus and sand.

6.1.2 Prepare the surface of the location to be tested so that it is a level plane. The plate makes an excellent tool for striking the surface to a neat level plane.

6.1.3 Seat the base plate on the plane surface, making sure there is good contact with ground surface around the edge of the flange at center hole. Mark the outline of the base plate to check for movement during the test, and drive nails pushed into the soil adjacent to the edge of the plate or otherwise secure the plate against movement without disturbing the soil to be tested.

6.1.4 In soils where leveling is not successful, a preliminary test shall be run at this point measuring the volume bounded by the funnel plate and ground surface. Fill the space with sand from the apparatus, determine the mass of sand used to fill the space, refill the apparatus, and determine a new initial mass of apparatus and sand before proceeding with the test. After this measurement is completed, carefully brush the sand from the prepared surface.

NOTE 5—A second calibrated apparatus may be taken to the field when this condition is anticipated (instead of refilling and making a second mass determination). The procedure in 6.1.4 may be used for each test when the best possible accuracy is desired; however, it is usually not needed for most production testing where a relatively smooth surface is obtainable.

6.1.5 Dig the test hole inside the center hole in the base plate, being very careful to avoid disturbing the soil that will bound the hole. Test-hole volumes shall be as large as practical to minimize the effects of errors and shall in no case be smaller than the volume indicated in Table 1. The sides of the hole should slope inward slightly toward the bottom that should be reasonably flat or concave. The hole should be kept as free as possible of pockets, overhangs, and sharp obtrusions since these affect the accuracy of the test. Soils that are essentially granular require extreme care and may require digging a conical-shaped test hole. Place all excavated soil and soil loosened during excavation in a container that is marked to identify the test number. Take care to avoid losing any material. Protect this material from any loss of moisture until the mass has been determined and a specimen has been obtained for moisture

content determination.

6.1.6 Clean the flange of the center hole in the metal plate, invert the apparatus, and seat the large metal funnel into the flanged hole at the same location as marked during calibration. Open the valve and allow the sand to fill the hole, funnel, and base plate. Take care to avoid jarring or vibrating the apparatus or the ground during this step. When the sand stops flowing, close the valve.

6.1.7 Determine the mass of the apparatus with remaining sand, and calculate the mass of sand used in the test.

6.1.8 Determine the mass of the material that was removed from the test hole.

6.1.9 Mix the material thoroughly and obtain a representative specimen for moisture-content determination or use the entire sample.

6.1.10 Determine the moisture content in accordance with Method D 2216.

NOTE 6—Rapid methods of moisture determination may be used to obtain an approximate value that is later verified or corrected according to the values obtained in accordance with Method D 2216.

6.2 Moisture-content specimens are to be large enough and selected in such a way so as to represent all the material obtained from the test hole. Suggested minimum mass of moisture specimens in relation to maximum particle size are shown in Table 1.

7. Calculations

7.1 Calculations as shown are for using units in grams and cubic centimetres or millilitres. Other units are permissible provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations.

7.2 Sand Calibration—Method A:

7.2.1 Calculate the bulk density of the sand as follows:

$$\rho_1 = M_1/V_1$$

where:

ρ_1 = bulk density of the sand, g/cm³, or multiply by 62.43 for lb/ft³,

M_1 = mass of sand to fill the known volume container, 5.4.9, g, and

V_1 = volume of the known volume container, 5.4.2, cm³.

7.3 Sand Calibration—Method B:

7.3.1 Calculate the volume of the density apparatus as follows:

$$V_2 = GT$$

where:

V_2 = volume of the density apparatus, mL,

G = mass of water required to fill the apparatus, 5.5.9, and

T = water temperature-volume correction shown in column 3 of Table 2.

7.3.2 Calculate the bulk density of the sand as follows:

$$\rho_1 = M_2/V_2$$

where:

ρ_1 = bulk density of the sand, g/cm³, or multiply by 62.43 for lb/ft³,

M_2 = mass of sand required to fill the apparatus 5.5.16, g, and

V_2 = volume of apparatus, 5.5.10.

7.5 Field Test:

7.5.1 Calculate the volume of the test hole as follows:

$$V = (M_3 - M_4)/\rho_1$$

where:

V = volume of the test hole, cm³,

M_3 = mass of sand to fill the test hole, funnel, and base plate, 6.1.7, g,

M_4 = mass of sand to fill the funnel and base plate, 5.2.5, g, and

ρ_1 = bulk density of the sand, 7.2.1 or 7.3.2, g/cm³.

7.5.2 Calculate the dry mass of material removed from the test hole as follows:

$$M_6 = 100 M_5/(w + 100)$$

where:

w = percentage of moisture, in material from test hole, 6.1.10,

M_5 = moist mass of the material from the test hole, 6.1.8,

M_6 = dry mass of material from test hole, g, or multiply by 0.002205 for lb.

7.5.3 Calculate the in-place wet and dry density of the material tested as follows:

$$\rho_m = M_5/V$$

$$\rho_d = M_6/V$$

where:

V = volume of test hole, 7.5.1, cm³,

M_5 = moist mass of the material from the test hole, 6.1.8, g,

M_6 = dry mass of the material from the test hole, 7.5.2, g,

ρ_m = wet density of the tested material g/cm³ or multiply by 62.43 for lb/ft³, and

ρ_d = dry density of the tested material.

8. Precision and Accuracy

TABLE 1 Minimum Test Hole Volumes and Minimum Moisture Content Samples Based on Maximum Size of Particle

Maximum Particle Size	Minimum Test Hole Volume, cm ³	Minimum Test Hole Volume, ft ³	Minimum Moisture Content Sample, g
No. 4 Sieve (4.75 mm)	710	0.025	100
½ in. (12.5 mm)	1420	0.050	300
1 in. (25 mm)	2120	0.075	500
2 in. (50 mm)	2830	0.100	1000

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methods provide absolute values of the density of soil in place against which this method may be compared. The variability of soil and the destructive nature of the test do not provide for repetitive duplication of test results to obtain meaningful statistical evaluation. Accuracy is a function of the care exercised in performing the steps of the test giving particular attention to careful control to systematic repetition of procedures used.

Temperature

Temperature		Volume of Water mL/g
°C	°F	
12	53.6	1.00048
14	57.2	1.00073
16	60.8	1.00103
18	64.4	1.00138
20	68.0	1.00177
22	71.6	1.00221
24	75.2	1.00268
26	78.8	1.00320
28	82.4	1.00375
30	86.0	1.00435
32	89.6	1.00497

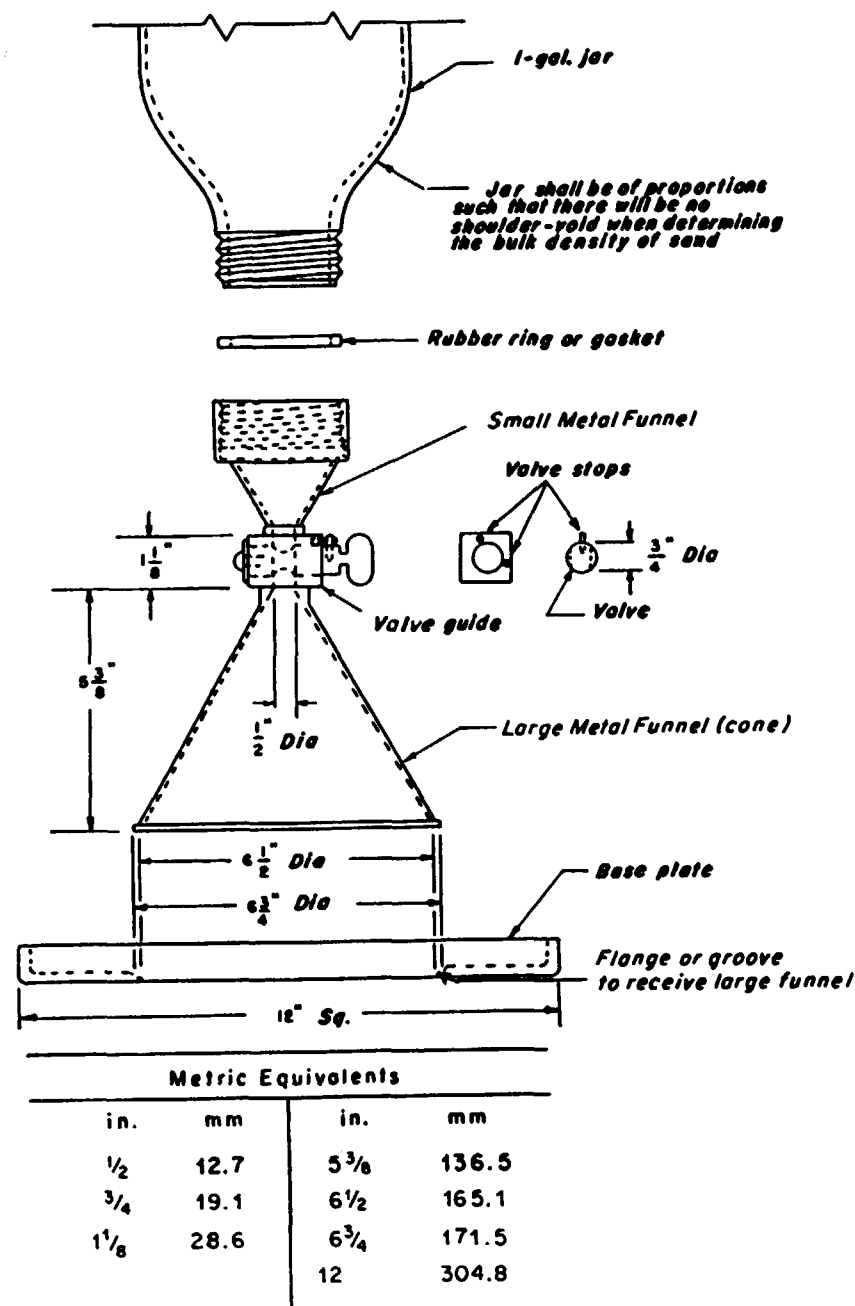


FIG. 1 Density Apparatus

where

C' = percent cement corrected for moisture variation,

C = percent cement determined from test sample,

R = percent material retained on a 4.75-mm sieve for the calibration samples,

M' = percent moisture of test sample as determined in Note 2, and

V_w , W_f and W_c are quantities computed in Section 6 for calibration Set 2.

10. Precision and Accuracy

10.1 In the process of development of

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D 2901-70, interlaboratory testing programs were conducted in 1967 and 1968. Results of these tests showed an average error in cement content determination of 3.6 % [(error)/(cement content) \times 100] from which a coefficient of variation of 4.5 % is estimated. On duplicate specimens used in the calibration process, the average deviation in millilitres of EDTA was 2.4 % [(deviation in millilitres)/(average millilitres) \times 100].

10.2 Changes incorporated in the 1982 revision are intended to improve precision and accuracy over that of D 2901-70.



Standard Test Methods for DENSITY OF SOIL AND SOIL-AGGREGATE IN PLACE BY NUCLEAR METHODS (SHALLOW DEPTH)¹

This standard is issued under the fixed designation D 2922; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

INTRODUCTION

These methods describe determination of the density of soil and soil-aggregate in place using nuclear equipment. In general, the total or wet density of the material under test is determined by placing a gamma source and a gamma detector either on, into, or adjacent to the material under test. These variations in test geometry are presented as the backscatter, direct transmission, or optional air gap approaches. The intensity of radiation detected is dependent in part upon the density of the material under test. The radiation intensity reading is converted to measured wet density by a suitable calibration curve. Principles of the nuclear test are discussed in the Appendix, as are some of its advantages and disadvantages. It should be noted that the density determined by these methods is not necessarily the average density within the volume involved in the measurement and that the equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken.

1. Scope

1.1 These methods cover the determination of the total or wet density of soil and soil-aggregate in place by the attenuation of gamma rays where the gamma source or gamma detector, or both, remain at or near the surface. The methods described are normally suitable to a test depth of approximately 2 to 12 in. (50 to 300 mm), depending on the test geometry used.

1.2 Three methods are described as follows:

	Section
Method A—Backscatter	9
Method B—Direct Transmission	10
Method C—Air Gap (Optional)	11

1.3 The values tested in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units may be approximate.

2. Applicable Documents

2.1 ASTM Standards:

D 1556 Test Method for Density of Soil in Place by the Sand-Cone Method²

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber-Balloon Method²

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures²

D 3017 Test Method for Moisture Content of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)²

3. Significance and Use

3.1 The methods described are useful as rapid, nondestructive techniques for the in-place determination of wet density of soil and

¹ These methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock.

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² Annual Book of ASTM Standards, Vol 04.08.

soil-aggregate. The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material within the zone of influence for each test is homogeneous.

3.2 Test results may be affected by chemical composition, sample heterogeneity, and the surface texture of the material being tested. The techniques also exhibit spatial bias in that the apparatus is more sensitive to certain regions of the material under test.

4. Calibration

4.1 Laboratory calibration of the gage is established by determining the nuclear count rate of each of several materials at different and known densities and establishing a relationship between count rate and density. Sufficient data should be taken at each density to ensure a precision of at least twice the normal precision obtained in field use. Calibration can be accomplished by either laboratory or field methods. Laboratory methods are recommended due to the higher inherent accuracy of laboratory standards and instruments as opposed to field methods which require the volume measurement of an excavated hole.

NOTE 1—Different chemical compositions of the blocks or other materials can affect the count rate. Calibration curves may not be applicable to materials not represented in establishing the calibration curve.

4.1.1 Laboratory calibration should involve the use of a minimum of five homogeneous blocks sufficiently large to represent an infinite volume to the nuclear instrument. The density of these standards shall be determined to an accuracy of $\pm 0.2\%$ ($\pm 0.3 \text{ lb/ft}^3$ at 160 lb/ft^3 or $\pm 5 \text{ kg/m}^3$ at 2565 kg/m^3). Three of the standards shall be constructed of materials having gamma mass attenuation coefficients within $\pm 1.0\%$ of each other over the range of gamma energy utilized by the gage for density measurement. These standards will be used to establish the gage response to density variations in the range from 100 to 170 lb/ft^3 (1600 to 2725 kg/m^3). The last two standards shall be materials that equally bracket the gamma mass attenuation coefficient of soils. Suggested materials are limestone and granite. The gage response will then be rotated about the zero density point on a plot or graphical representation such that it falls halfway between the limestone and granite data. This final response

will be used in the field for measurement.

4.1.2 Field calibration may be used where laboratory calibration facilities are not available or where it becomes necessary to calibrate the instrument for materials that chemically are different than soils. A minimum of ten field tests should be used for establishing calibration by the field method so that a range of densities and materials will be represented. The sand-cone method in accordance with Test Method D 1556 or the rubber-balloon method in accordance with Test Method D 2167 may be used to determine the wet range of density of carefully selected field sites on which density data have been previously determined. As an alternative, nuclear data can be obtained on prepared containers of soil and soil-aggregate compacted to known densities. The containers must be sufficiently large to represent an infinite volume to the nuclear instrument. Data from either of these methods may be used to establish a new gage response by visually fitting a line to a plot of gage response to density over the range of densities found in the samples. It is more desirable to use the latter data, to rotate the laboratory calibration in 4.1.1, or a constant offset from this laboratory calibration, to fit the field data. Extreme care must be exercised in the determination of wet density in either the field sites or prepared containers. Because of the variability and scatter inherent in field tests and container preparation and compaction, this method is considered less accurate than techniques using calibration blocks.

NOTE 2—Use of blocks is advantageous because they are durable and provide stable density references. Blocks and prepared containers must be large enough not to change the observed count rate (or count ratio) if made larger in any dimensions. Dimensions of approximately 12 in. (300 mm) width by 14 in. (360 mm) depth by 22 in. (560 mm) length have proven satisfactory for equipment now available. For calibration of backscatter only, a depth of not less than 9 in. (230 mm) is adequate.

4.2 *Checking and Adjusting Calibration Data*—The calibration data for newly acquired instruments, instruments for which the calibration is more than one year old, or instruments that have been damaged and repaired may be checked by using the method of 4.1.2. A minimum of ten field tests must be used to compare with the existing calibration data in order to justify changing the calibration.

4.2.1 If each of the field tests varies by not

more than 3% from the nuclear density and some of the field densities are greater and some less than the nuclear density, then adjustment of the calibration is not necessary.

4.2.2 If all of the field tests are more or all less than the nuclear density and the average of the difference exceeds 1%, then adjust each subsequent nuclear density by the average difference.

4.2.3 The average difference found in 4.2.2 may be used to determine a new calibration response. Either rotation about a zero point or constant offset from the original calibration may be used.

NOTE 3—Adjusting calibration curves is a complex task and it should be attempted only by those knowledgeable in this field. Most manufacturers either provide this service or will offer assistance to the user.

5. System Specifications

5.1 Any equipment that is used under the requirements of this method shall satisfy the following specifications:

5.1.1 *Precision*—Precision of the system is determined from the slope of the calibration response and the statistical deviation of the count for the recommended period of measurement, which shall be at least 1 min:

$$P = \sigma/S \quad (1)$$

where:

P = precision,

σ = standard deviation, counts per measurement period, and

S = slope, Δ counts per measurement period/ (lb/ft^3) or (kg/m^3) .

5.1.1.1 Determine the slope of the counts per measurement period at a unit weight of 125 lb/ft^3 (2000 kg/m^3). This can usually be determined from the calibration response and must be the true counts from the detector system before the display. Determine the counts per measurement period at the same density by the same method. The precision can be calculated by:

$$P = \sqrt{C/PC}/S \quad (2)$$

where:

P = precision,

C = counts per measurement period,

S = slope, Δ counts per measurement period/ (lb/ft^3) or (kg/m^3) , and

PC = amount of prescale (Note 4) applied to

the detector counts prior to display. The manufacturer will supply this value. If no prescale is built into the equipment, the value is 1.

NOTE 4—The value of prescale is the number by which the total count rate of the detector(s) is divided before display on the readout to eliminate the need for displaying non-significant digits. The value of P at a density of 125 lb/ft^3 (2000 kg/m^3) shall be no greater than $\pm 1.0 \text{ lb/ft}^3$ ($\pm 16 \text{ kg/m}^3$) for the backscatter methods nor greater than $\pm 0.35 \text{ lb/ft}^3$ ($\pm 6 \text{ kg/m}^3$) for direct transmission method.

5.1.1.2 If 5.1.1 cannot be performed as above, the precision can be computed by determining the standard deviation of at least 20 repetitive measurements (gage not moved after the first measurement) of material having density of $125.0 \pm 5.0 \text{ lb/ft}^3$ ($2000 \pm 80 \text{ kg/m}^3$). In order to perform this procedure, the resolution of the count display, calibration response, or other method of displaying density must be equal to or better than $\pm 0.1 \text{ lb/ft}^3$ ($\pm 1.6 \text{ kg/m}^3$).

5.1.2 *Chemical Error*—The error due to changes in chemical composition of materials having gamma mass attenuation coefficients less than those of granite or greater than those of limestone shall be not greater than $\pm 2.5\%$ of backscatter methods and $\pm 1.2\%$ for direct transmission with the source at a depth of 6 in. (150 mm).

5.1.2.1 If the instrument was originally calibrated by the method described in 4.1.1, then the chemical error can be easily determined by using the standard block data which was taken to determine the gage response. Using the gage count rate on the limestone standard and the calibrated gage response, determine the gage density of the limestone standard. This will normally be higher than the true density. Compute the percent error. Repeat the same procedure for the granite standard. This will normally be lower than the true density. The difference between the two percent errors (taking into account the sign of the error) divided by two will equal the chemical error.

5.1.2.2 If the gage was calibrated by some means other than 4.1.1 or if the original calibration data are not available, then other means must be used to determine the chemical error. Using the procedure of 5.1.2.1, the relative densities of the limestone and granite standard blocks were not important, but using this procedure the standards should preferably be



within 5 lb/ft³ (80 kg/m³) of each other in order to eliminate the possibility of an improper calibration which could cause good accuracy and small chemical error at the limestone and granite density but with large errors at all other densities. A high-density limestone or marble standard is suggested. First measure the density and compute the percent error on each standard. The chemical error is then the difference between the two errors divided by two. The sum of the two errors represents the calibration accuracy.

5.1.3 Surface Roughness Error—The error caused by a 0.050-in. (1.3-mm) air gap introduced between the base of the gage and the surface of the material being measured should cause an error of no more than 4% in the backscatter method nor more than 1% in the direct-transmission method with the source placed at a 6-in. (150-mm) depth. Older models of instruments currently in use may not meet this requirement. The users can minimize the effects of surface roughness by careful site preparation.

5.1.3.1 The effect of surface roughness can be measured by placing the instrument on a smooth flat surface after cleaning both the surface and the gage base and measuring the density. Next, elevate the gage by placing 0.050-in. (1.3-mm) spacers between the gage base and the material surface in such a way as to not interfere with the gage measurement zone. Remeasure the apparent density; the difference represents the gage error.

6. Safety Precaution

6.1 This equipment utilizes radioactive materials which may be hazardous to the health of the users, unless proper precautions are taken. Users of this equipment must become completely familiar with possible safety hazards and with all applicable government regulations. Effective operator instruction together with routine safety procedures such as source-leak tests, recording and elevation of film badge data, use of survey meters, etc., are an essential part of the operation of equipment of this type.

7. Apparatus

7.1 The apparatus may consist of items to perform Method A—Backscatter, Method B—Direct Transmission, or a combination of both.

Items listed are common to both apparatus except where noted as Method A or Method B only. Apparatus for Method C—Air Gap (optional) is detailed in Section 11.

7.2 Gamma Source—An encapsulated and sealed radioactive source meeting the specific form requirements of Title 49 of the Code of Federal Regulations.

7.3 Gamma Detector—Any suitable type.

7.4 Readout Device—A suitable scaler with a resolution and range to display counts over the range of density for which the apparatus will be used. Usually the scaler will also contain other electronic devices and the necessary electrical power for operation.

7.5 Housing—The source, detector, readout device, etc., shall be in housings of rugged construction that are moisture- and dustproof. For Method B use, the housing shall contain a means of locating either the source or detector at a distance of 2 to 12 in. (50 to 300 mm) into a preformed hole in the material to be tested. The probe containing the source or detector shall be sufficiently rigid so as to maintain a constant distance along the measuring path length and also contain markings to indicate the depth to which the probe has been placed.

NOTE 5—The gamma source, detector, readout device, and power supply may be housed separately or combined and integrated with a nuclear moisture-measuring system.

7.6 Reference Standard—A device that isolates the instrument and provides a means of allowing the instrument to make a measurement that is constant within the reproducibility of the system. All calibrations will be made as a ratio to the reference standard count and all field measurements will be taken as a ratio to the reference standard count.

7.7 Site-Preparation Devices

7.7.1 Method A equipment shall include a flat plate straightedge, or other suitable tool to be used to level the test site to the required smoothness.

7.7.2 Method B equipment shall, in addition to the above, include a hole-forming device such as an auger or pin having a nominal diameter equal to or up to 1/4 (3 mm) larger than the probe and also a guide to ensure that the hole is perpendicular to the test site surface.

7.8 Transport Case—Each system shall include a shipping and transport case to house

the equipment and shall meet the U.S. Department of Transportation requirements in Title 49 of the Code of Federal Regulations. The exterior of the case shall contain all labels required by the regulations and radiation levels shall meet the "Yellow II" standards.

8. Standardization

8.1 All nuclear density instruments are subject to long-term aging of the radioactive source, detectors, and electronic systems, which may change the relationship between count rate and density. To offset this aging, all instruments are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard. The reference count rate should be in the same order of magnitude or higher than the range of measurement count rates over the useful density range of the equipment.

8.2 Standardization of equipment on the reference standard is required at the start of each day's use and a permanent record of these data should be retained.

8.3 Turn on the equipment and allow for stabilization of the equipment in accordance with the manufacturer's recommendations.

8.4 Take at least four repetitive readings at the normal measurement period and obtain the mean. If available on the instrument, one measurement at a period of four times the normal period is acceptable. This constitutes one standardization check.

8.5 If the value obtained above is within the limits set by Eq 3, the equipment is considered to be in satisfactory condition and may be used. If the value obtained is outside the limits set by Eq 3, another standardization check should be made. If the second standardization check is within the limits, the equipment may be used; but if it also fails the test, the equipment should be checked as recommended by the manufacturer and the calibration checked (4.2) or recalibrated, or both.

$$N_s = N_n \pm 2.0 \sqrt{N_n} / PC \quad (3)$$

where:

N_s = value of current standardization check (8.4) on the reference standard (7.6).

N_n = average of the past four values of N_s taken for prior usage, and

PC = amount of prescale applied to the detector counts prior to display. The manu-



facturer will supply this value. If no prescale is built into the equipment, the value is 1.

8.6 The value of N_s (8.4) will be used to determine the count ratios for the current day's use of the equipment. If, for any reason, measured densities become suspect during the day's use, another standardization should be performed.

NOTE 6—If the instrument is to be used either continuously or intermittently during the day, it is generally best to leave it in the "power on" or "standby" condition during the day to prevent having to repeat the standardization. This will provide more stable, consistent results.

NOTE 7—Standardization shall be performed in accordance with the manufacturer's recommendations and away from other radioactive sources, large masses of metal or vertical objects, free water, or other items that can affect the gage readings.

9. Procedure, Method A—Backscatter

9.1 Standardize the instrument (Section 8).

9.2 Select a test location where the gage in test position will be at least 9 in. (230 mm) away from any vertical projection.

9.3 Prepare the test site in the following manner:

9.3.1 Remove all loose and disturbed material and additional material as necessary to expose the top of the material to be tested.

NOTE 8—The spatial bias should be considered in determining the depth at which the gage is to be seated.

9.3.2 Prepare a horizontal area sufficient in size to accommodate the gage, by planing the area to a smooth condition so as to obtain maximum contact between the gage and material being tested.

9.3.3 The maximum void beneath the gage shall not exceed approximately 1/4 in. (3 mm). Use native fines or fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool.

NOTE 9—The placement of the gage on the surface of the material to be tested is critical to the successful determination of density. The optimum condition is total contact between the bottom surface of the gage and the surface of the material being tested. This is not possible in all cases. To correct surface irregularities, use of native fines or sand as a filler is necessary. The depth of the filler should not exceed approximately 1/4 in. (3 mm) and the total area filled should not exceed 10% of the bottom area of the gage. Several trial seatings may be required to achieve these conditions.

9.4 Proceed with the test in the following manner:

- 9.4.1 Seat the gage firmly.
- 9.4.2 Keep all other radioactive sources away from the gage to avoid affecting the measurement
- 9.4.3 Secure and record one or more readings for the normal measurement period.
- 9.4.4 Determine the ratio of the reading to the standard count (9.1). From this ratio and the calibration, determine the in-place wet density.

NOTE 10—Some instruments have built-in provisions to compute the ratio, compute the in-place wet density, and display it to the operator automatically.

10. Procedure, Method B — Direct Transmission

- 10.1 Standardize the instrument (Section 8).
- 10.2 Select a test location where the gage in test position will be at least 9 in. (230 mm) away from any vertical projection.
- 10.3 Prepare the test site in the following manner:

- 10.3.1 Remove all loose and disturbed material, and remove additional material as necessary to expose the top of the material to be tested.
- 10.3.2 Prepare a horizontal area, sufficient in size to accommodate the gage, by planing the area of a smooth condition so as to obtain maximum contact between the gage and material being tested.
- 10.3.3 The maximum void beneath the gage shall not exceed approximately $\frac{1}{8}$ in. (3 mm). Use native fines or fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool. The depth of the filler should not exceed approximately $\frac{1}{8}$ in. (3 mm).
- 10.3.4 Make a hole perpendicular to the prepared surface using the guide and the hole-forming device (7.6.2). The hole shall be of such depth and alignment that insertion of the probe will not cause the gage to tilt from the plane of the prepared area. The depth of the hole must be at least 2 in. (50 mm) deeper than the depth to which the probe will be placed. The guide shall be the same size as the base of the gage, with the hole in the same location on the guide as the probe on the gage. The corners of the guide are marked by scoring the surface of the soil.

10.4 Proceed with testing in the following manner:

- 10.4.1 Set the gage on the soil surface, carefully aligning it with the marks so that the probe will be directly over the pre-formed hole.
- 10.4.2 Insert the probe in the hole.
- 10.4.3 Seat the gage firmly by rotating it about the probe with a back and forth motion.
- 10.4.4 Pull gently on the gage in the direction that will bring the side of the probe against the side of the hole closest to the detector (or source) location in the gage housing.
- 10.4.5 Keep all other radioactive sources away from the gage to avoid affecting the measurement.
- 10.4.6 Secure and and record one or more readings for the normal measurement period.
- 10.4.7 Determine the ratio of the reading to the standard count (10.1). From the ratio and the calibration, determine the in-place wet density.

11. Procedure, Method C—Air Gap (Optional)

11.1 If the nuclear gage errors due to calibration using materials with different chemical composition are in excess of maximum error listed in 5.2, the air-gap method should be employed. It should be noted that the required use of two different site measurements may decrease the precision due to the statistics of the air gap measurement.

11.2 Apparatus:

- 11.2.1 All apparatus described in Section 1.
- 11.2.2 *Cradle or Spacers*, to support the gage at the optimum air gap above the material being tested. The cradles or spacers shall be designed as to support the gage at optimum height without shielding the base of the gage. Figure 1 shows a typical air-gap cradle that demonstrates the principle. The cradle shown in Fig. 1 is not the only satisfactory method. Other methods which support the gage at the optimum air gap without shielding the base of the gage are satisfactory.

NOTE 11—Air-gap calibration curves and optimum air gap may be furnished for each gage by the manufacturer and can be readily checked by the user.

11.3 *Determination of Optimum Air Gap*—To determine the optimum air gap for use in the air-gap method, proceed as follows:

- 11.3.1 Use three or more different areas on which to make determinations. These areas

may be either blocks (4.1.1) or field sites of compacted soil or soil-aggregate on which density data have been previously determined (4.1.2) or alternative prepared containers of soil or soil-aggregate compacted to known densities (4.1.2). The density of materials at the selected areas should vary through a range including the densities of the materials which will be tested.

11.3.2 Place the density gage over the test area. Support the gage by blocks placed at the extreme edges of the gage so as not to obstruct the space between the bottom of the gage and the surface of the test area.

11.3.3 Take and record readings for two normal measurement periods in counts per minute and determine the average of the readings.

11.3.4 By adding additional blocks or spacers, increase the air gap by $\frac{1}{4}$ in. (6.3 mm). Take and record, and average readings for two additional normal measurement periods.

11.3.5 Continue increasing the air gap by increments of $\frac{1}{4}$ in., securing average readings for each air gap (11.3.3) until there is a decrease in the counts per minute readings with an increase in air gap.

11.3.6 On an arithmetic scale, plot counts per minute as the ordinate *versus* each air gap (in inches or millimetres) and draw a smooth curve through the resulting points. Record the peak air gap determined at the peak of the curve.

11.3.7 Repeat procedures 11.3.2 through 11.3.6 over two or more additional areas of materials of different density, and record the peak air gap for each area.

11.3.8 Determine the average of the peak air gaps determined on all areas. This is the optimum air gap. Use the optimum air gap for establishing the calibration curve for the air-gap method, and for all determinations of density by the air-gap method.

11.4 Procedure:

- 11.4.1 Standardize the instrument.
- 11.4.2 Select a test location where the gage in test position will be at least 12 in. (300 mm) away from any vertical projection. Plan sufficient area to accommodate the gage and cradle.
- 11.4.3 Prepare the test site in the following manner:

- 11.4.3.1 Remove all loose and disturbed material, and additional material as necessary to expose the top of the material to be tested. (See

Note 8.)

11.4.3.2 Prepare a horizontal area, sufficient in size to accommodate the gage and cradle, by planing the area to a smooth condition so as to obtain maximum contact between the gage and material being tested.

11.4.3.3 The maximum void beneath the gage shall not exceed approximately $\frac{1}{8}$ in. (3 mm). Use native fines or fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool.

NOTE 12—The air-gap method requires taking one or more readings in both the backscatter position and the air-gap position. The placement of the gage on the surface of the material to be tested is critical to the successful determination of density. The optimum condition is total contact between the bottom surface of the gage and the surface of the material being tested. This is not possible in all cases and to correct surface irregularities use of sand or similar material as a filler is necessary. The depth of the filler should not exceed approximately $\frac{1}{8}$ in. (3 mm) and the total area filled should not exceed 10 % of the bottom area of the gage. Several trial seatings may be required to achieve these conditions.

11.4.4 Proceed with the test in the following manner:

- 11.4.4.1 Seat the gage firmly.
- 11.4.4.2 Keep all other radioactive sources away from the gage to avoid affecting the measurement so as not to affect the readings.
- 11.4.4.3 Secure and record one or more readings for the normal measurement period in the backscatter position.
- 11.4.4.4 Place the cradle, set at optimum air gap, on the test site, and place the gage on the cradle so that the gage is directly over the same site used for backscatter reading. When a direct-transmission type gage is used, set the probe in the retracted or backscatter position for this reading.
- 11.4.4.5 Take the same number of readings for the normal measurement period in the air-gap position as in the backscatter position (11.4.4.3).
- 11.4.4.6 Determine the air-gap ratio by dividing counts per minute obtained in the airgap position (11.4.4.5) by counts per minute obtained in backscatter position (11.4.4.3).
- 11.4.4.7 Determine the in-place wet density by use of the applicable calibration curve previously established.

NOTE 13—The air-gap ratio may be determined by dividing counts per minute obtained in the backscatter position by counts per minute obtained in the



air-gap position or *vice versa*. Whichever ratio is used, a calibration curve using the same ratio must also be used.

12. Determination of Dry Density

12.1 To obtain dry density, use one of the following alternative methods:

12.1.1 If the water content is determined by nuclear methods, Test Method D 3017, subtract the pounds per cubic foot (kg/m^3) of moisture from the pounds per cubic foot (kg/m^3) of wet density, and obtain dry density in pounds per cubic foot (kg/m^3).

12.1.2 If the water content is determined by other methods, such as oven drying, Method D 2216, carbide method, etc., and is in the form of percent, proceed as follows:

$$\rho_d = [\rho_m / (w + 100)] \times 100 \quad (4)$$

where:

ρ_d = dry density, lb/ft^3 (kg/m^3),

ρ_m = wet density, lb/ft^3 (kg/m^3), and

w = percent moisture in the specimen.

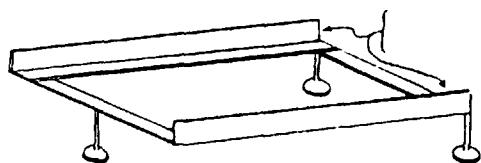
13. Report

13.1 The report shall include the following:

13.1.1 Location.

13.1.2 Elevation of surface.

13.1.3 Visual description of material.



Welded metal approx. 1 by 1 by 1/4 in. (25.4 by 25.4 by 3.2 mm) angle

FIG. 1 Typical Air-Gap Cradle

APPENDIX

XI. NOTES ON THE NUCLEAR TEST

X1.1 The equipment used in this method is of the surface type as opposed to that designed for use in deep borings. In general, and neglecting the associated electronics, this equipment consists of three principal elements: (1) a nuclear source emitting gamma rays, (2) a detector sensitive to these rays as they are modified by passing through the material

13.1.4 Identification of test equipment (make, model, and serial number),

13.1.5 N_m , average of the past four values of N , taken for prior usage,

13.1.6 N_s , value of the current standardization check (8.3) on the reference standard (7.5), and the method and date of standardization,

13.1.7 Count rate for each reading,

13.1.8 Count ratio,

13.1.9 Wet density.

NOTE 14—The count rate for each reading (13.1.7) and the count ratio (13.1.8) may be omitted from the report for instruments that have built-in provisions to take the ratio, compute the in-place wet density, and display it to the operator automatically.

14. Precision and Accuracy

14.1 The precision and accuracy of this standard has not been determined. No methods are available that provide absolute values of the density of soil or soil-aggregate mixtures in place against which these methods can be compared. The variability of soil does not permit duplication of test results for obtaining a meaningful statistical evaluation. Accuracy is a function of the care exercised in performing the calibrations and steps of the test and of the variability of the material being tested.

being tested, and (3) a counter or scaler with provisions for automatic and precise timing, for determining the rate at which the modified gamma rays arrive at the detector. While rate meters are suitable, in principle, scalars are commonly used. In general, any source of gamma rays that are sufficiently numerous and properly energetic can be used in measuring the

density of soil and soil-aggregate. Source stability with time, in terms of half-life, is an important design consideration and the sources most commonly used are cesium-137 and radium-226. The two detectors most commonly used are gas-filled tubes of the Geiger-Müller type and scintillation crystals, usually of sodium-iodide. Detectors of the latter type offer the potential of electronically varying the range of energies of the gamma rays that are counted. With detectors of the Geiger-Müller type, this range is fixed in the design. For most available equipment, the source-detector geometry is fixed for backscatter pages and is adjustable to various preselected depths of direct transmission gages.

X1.2 Measurements are made using gamma rays that largely reflect at reduced energy by scattering in, or by, direct transmission through the material under test. In backscatter, the rays are emitted into the material from near its surface and some are deflected at reduced energy back to the detector, largely by Compton scattering. In direct transmission the source or detector is inserted in the test materials and, in contrast to the backscatter method, some of the emitted and unshielded rays can presumably follow a straight-line path to the detector. In either source-detector arrangement, the number of rays reaching the detector is, over-all, a nonlinear function of the density of the material being tested. For the usual range of soil and soil-aggregate densities the relationship is such that the higher the density of a given material, the lower the count rate.

X1.3 The determination of density by the nuclear means of this method is indirect. To date no theoretical approach has been developed that predicts the count rate for given equipment, geometry, material, and density. As a result, the relationship between material density and nuclear-count rate is determined by correlation tests of materials at known average densities. Individual equipment manufacturers supply a calibration curve with each set of their equipment. It has been found that these curves do not necessarily hold for all soils and soil-aggregates because of differences in chemical composition. Apparent variations in calibration may also be induced by differences in seating, in background count, and other test variations. Because of these considerations, provisions are included in this method for checking for variations or changes. Different approaches may be used in checking calibration and those in more general use are given. For good practice, these calibration procedures should be followed with newly purchased equipment and with major component replacements of in-service equipment.

X1.4 The density determined by this method is the wet or total density. It should be noted that the volume of soil or soil-aggregate represented in the measurements is indeterminate and will vary with the source-detector geometry of the equipment used and with the characteristics of the material tested. In general, and with all other conditions constant, the more dense the material, the smaller the volume involved in the measurement. The density so determined is not necessarily the average density within the volume involved in the measurement. Although for the usual surface backscatter test equipment and



materials the gages are influenced by 6 to 7 in. (150 to 175 mm) of material, the top 1 in. (25 mm) of the material determines about one half of the measured count rate with the result that the observed density is largely determined by the density of the upper layers. For usual density conditions, the total count is largely determined by the upper 3 to 4 in. (75 to 100 mm) of soils and soil-aggregates. Where these materials are of uniform density, this characteristic of this method is of no effect. With direct-transmission gages the effect of vertical density variations may be eliminated. Other problems, however, can be introduced in the mechanics of inserting the source or the detector.

X1.5 The number of gamma rays emitted from a given source over a given time period are statistically random and follow a Poisson distribution. Because of this, the actual number of modified rays that are detected and counted in the density-measuring process should be sufficiently large to minimize the probability that the observed count reflects unacceptable variations. This is reflected in the standard deviation which is the square root of the total count. The overall system accuracy in determining densities is also statistical in nature and appears to vary with the equipment used, the test conditions of laboratory versus field, as well as with materials and operators. Because of these variables, it is not possible to give precise numbers for system accuracy and precision of these methods. It is believed, however, that if the procedures herein are carefully followed, the standard deviation of the nuclear measured values, in terms of accuracy, will not be greater than on the order of some 3 lb/ft^3 (50 kg/m^3). In terms of precision or repeatability, determined without moving the test equipment, this should not be greater than on the order of 1 lb/ft^3 (20 kg/m^3).

X1.6 One of the most commonly used sources, cesium-137, is man made and as such its use is regulated by the Federal Government through the Atomic Energy Commission as well as by some state and local governments. Because radium is a naturally occurring material, its use is not now regulated by the Federal Government but is by some state and local governments. Among others, the objectives of these regulations are the use of radioactive materials in a manner safe to the operator and all others. Attention is directed to Section 6, Safety Precaution.

X1.7 The in-place nuclear density tests of this method offer several advantages over the older conventional methods (sand-cone, rubber-balloon, etc.), particularly in tests performed for the continuing control of construction. Among these, perhaps the principal advantage is the relative ease with which the test can be performed, thus freeing the operator from the physical tasks of digging holes and collecting and weighing bulky samples. However, it sacrifices the opportunity to examine the soil in depth. If information is sought on in-place densities only, and test determinations of maximum density are not involved, many more tests can be performed per day than by the older methods. In addition, apparently erratic measurements can be immediately detected and checked since the nuclear tests are more nearly nondestructive. These advantages accrue to organi-



D 2922

zations that are engaged in density measurements on a more or less continuous basis. Organizations that make infrequent or occasional density determinations may find that the advantages of the nuclear method

can be offset by maintenance and start-up considerations such as periodically charging batteries, maintaining radiation exposure records, etc.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.



Designation: D 2936 - 84

Standard Test Method for DIRECT TENSILE STRENGTH OF INTACT ROCK CORE SPECIMENS¹

This standard is issued under the fixed designation D 2936; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the direct tensile strength of intact cylindrical rock specimens.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 ASTM Standards:

E 4 Practices for Load Verification of Testing Machines²

E 122 Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process³

3. Significance and Use

3.1 Rock is much weaker in tension than in compression. Thus, in determining the failure condition for a rock structure, many investigators employ the tensile strength of the component rock as the failure strength for the structure. Direct tensile stressing of rock is the most basic test for determining the tensile strength of rock.

4. Apparatus

4.1 *Loading Device*, to apply and measure axial load on the specimen, of sufficient capacity to apply the load at a rate conforming to the requirements of 6.2. The device shall be verified

at suitable time intervals in accordance with the procedures given in Practices E 4 and shall comply with the requirements prescribed therein.

4.2 *Caps*—Cylindrical metal caps that, when cemented to the specimen ends, provide a means through which the direct tensile load can be applied. The diameter of the metal caps shall not be less than that of the test specimen, nor shall it exceed the test specimen diameter by more than 0.0625 in. (1.6 mm). Caps shall have a thickness of at least 1 1/4 in. (32 mm). Caps shall be provided with a suitable linkage system for load transfer from the loading device to the test specimen. The linkage system shall be so designed that the load will be transmitted through the axis of the test specimen without the application of bending or torsional stresses. The length of the linkages at each end shall be at least two times the diameter of the metal end caps. One such system is shown in Fig. 1.

NOTE 1—Roller or link chain of suitable capacity has been found to perform quite well in this application. Because roller chain flexes in one plane only, the upper and lower segments should be positioned at right angles to each other to effectively reduce bending in the specimen. Ball-and-socket, cable, or similar arrangements have been found to be generally unsuitable as their tendency for bending and twisting makes the assembly unable to transmit a purely direct tensile stress to the test specimen.

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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² *Annual Book of ASTM Standards*, Vols 03.01, 04.02, 07.01, and 08.03.

³ *Annual Book of ASTM Standards*, Vol 14.02.



Standard Practice for THIN-WALLED TUBE SAMPLING OF SOILS¹

This standard is issued under the fixed designation D 1587; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This practice has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specifications and Standards.

1. Scope

1.1 This practice covers a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests of structural properties. Thin-walled tubes used in piston, plug, or rotary-type samplers, such as the Denison or Pitcher, must comply with the portions of this practice which describe the thin-walled tubes (5.3).

NOTE 1—This practice does not apply to liners used within the above samplers.

2. Applicable Documents

2.1 ASTM Standards:

- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)²
- D 3550 Practice for Ring-Lined Barrel Sampling of Soils²
- D 4220 Practices for Preserving and Transporting Soil Samples²

3. Summary of Practice

3.1 A relatively undisturbed sample is obtained by pressing a thin-walled metal tube into the in-situ soil, removing the soil-filled tube, and sealing the ends to prevent the soil from being disturbed or losing moisture.

4. Significance and Use

4.1 This practice, or Practice D 3550, is used when it is necessary to obtain a relatively undisturbed specimen suitable for laboratory tests of structural properties or other tests that might be influenced by soil disturbance.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole; that does not disturb the soil to be

sampled; and that does not hinder the penetration of the thin-walled sampler. Open borehole diameter and the inside diameter of driven casing or hollow stem auger shall not exceed 3.5 times the outside diameter of the thin-walled tube.

5.2 *Sampler Insertion Equipment*, shall be adequate to provide a relatively rapid continuous penetration force. For hard formations it may be necessary, although not recommended, to drive the thin-walled tube sampler.

5.3 *Thin-Walled Tubes*, should be manufactured as shown in Fig. 1. They should have an outside diameter of 2 to 5 in. and be made of metal having adequate strength for use in the soil and formation intended. Tubes shall be clean and free of all surface irregularities including projecting weld seams.

5.3.1 *Length of Tubes*—See Table 1 and 6.4.

5.3.2 *Tolerances*, shall be within the limits shown in Table 2.

5.3.3 *Inside Clearance Ratio*, should be 1 or as specified by the engineer or geologist for the soil and formation to be sampled. Generally the inside clearance ratio used should increase with the increase in plasticity of the soil being sampled. See Fig. 1 for definition of inside clearance ratio.

5.3.4 *Corrosion Protection*—Corrosion, whether from galvanic or chemical reaction, can damage or destroy both the thin-walled tube and the sample. Severity of damage is a function of

¹ This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Tests for Soil Investigations.

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² Annual Book of ASTM Standards, Vol 04.08.

time as well as interaction between the sample and the tube. Thin-walled tubes should have some form of protective coating. Tubes which will contain samples for more than 72 h shall be coated. The type of coating to be used may vary depending upon the material to be sampled. Coatings may include a light coat of lubricating oil, lacquer, epoxy, Teflon, and others. Type of coating must be specified by the engineer or geologist if storage will exceed 72 h. Plating of the tubes or alternate base metals may be specified by the engineer or geologist.

5.4 *Sampler Head*, serves to couple the thin-walled tube to the insertion equipment and, together with the thin-walled tube, comprises the thin-walled tube sampler. The sampler head shall contain a suitable check valve and a venting area to the outside equal to or greater than the area through the check valve. Attachment of the head to the tube shall be concentric and coaxial to assure uniform application of force to the tube by the sampler insertion equipment.

6. Procedure

6.1 Clean out the borehole to sampling elevation using whatever method is preferred that will ensure the material to be sampled is not disturbed. If groundwater is encountered, maintain the liquid level in the borehole at or above ground water level during the sampling operation.

6.2 Bottom discharge bits are not permitted. Side discharge bits may be used, with caution. Jetting through an open-tube sampler to clean out the borehole to sampling elevation is not permitted. Remove loose material from the center of a casing or hollow stem auger as carefully as possible to avoid disturbance of the material to be sampled.

NOTE 2—Roller bits are available in downward-jetting and diffused-jet configurations. Downward-jetting configuration rock bits are not acceptable. Diffused-jet configurations are generally acceptable.

6.3 Place the sample tube so that its bottom rests on the bottom of the hole. Advance the sampler without rotation by a continuous relatively rapid motion.

6.4 Determine the length of advance by the resistance and condition of the formation, but the length shall never exceed 5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clays.

NOTE 3—Weight of sample, laboratory handling ca-

pabilities, transportation problems, and commercial availability of tubes will generally limit maximum practical lengths to those shown in Table 1.

6.5 When the formation is too hard for push-type insertion, the tube may be driven or Practice D 3550 may be used. Other methods, as directed by the engineer or geologist, may be used. If driving methods are used, the data regarding weight and fall of the hammer and penetration achieved must be shown in the report. Additionally, that tube must be prominently labeled a "driven sample."

6.6 In no case shall a length of advance be greater than the sample-tube length minus an allowance for the sampler head and a minimum of 3 in. for sludge-end cuttings.

NOTE 4—The tube may be rotated to shear bottom of the sample after pressing is complete.

6.7 Withdraw the sampler from the formation as carefully as possible in order to minimize disturbance of the sample.

7. Preparation for Shipment

7.1 Upon removal of the tube, measure the length of sample in the tube. Remove the disturbed material in the upper end of the tube and measure the length again. Seal the upper end of the tube. Remove at least 1 in. of material from the lower end of the tube. Use this material for soil description in accordance with Practice D 2488. Measure the overall sample length. Seal the lower end of the tube. Alternatively, after measurement, the tube may be sealed without removal of soil from the ends of the tube if so directed by the engineer or geologist.

NOTE 5—Field extrusion and packaging of extruded samples under the specific direction of a geotechnical engineer or geologist is permitted.

NOTE 6—Tubes sealed over the ends as opposed to those sealed with expanding packers should contain end padding in end voids in order to prevent drainage or movement of the sample within the tube.

7.2 Prepare and immediately affix labels or apply markings as necessary to identify the sample. Assure that the markings or labels are adequate to survive transportation and storage.

8. Report

8.1 The appropriate information is required as follows:

- 8.1.1 Name and location of the project,
- 8.1.2 Boring number and precise location on project,

- 8.1.3 Surface elevation or reference to a datum,
 8.1.4 Date and time of boring—start and finish,
 8.1.5 Depth to top of sample and number of sample,
 8.1.6 Description of sampler: size, type of metal, type of coating,
 8.1.7 Method of sampler insertion: push or drive,
 8.1.8 Method of drilling, size of hole, casing, and drilling fluid used,
 8.1.9 Depth to groundwater level: date and

- time measured,
 8.1.10 Any possible current or tidal effect on water level,
 8.1.11 Soil description in accordance with Practice D 2488,
 8.1.12 Length of sampler advance, and
 8.1.13 Recovery: length of sample obtained.

9. Precision and Bias

9.1 This practice does not produce numerical data; therefore, a precision and bias statement is not applicable.

TABLE 1 Suitable Thin-Walled Steel Sample Tubes⁴

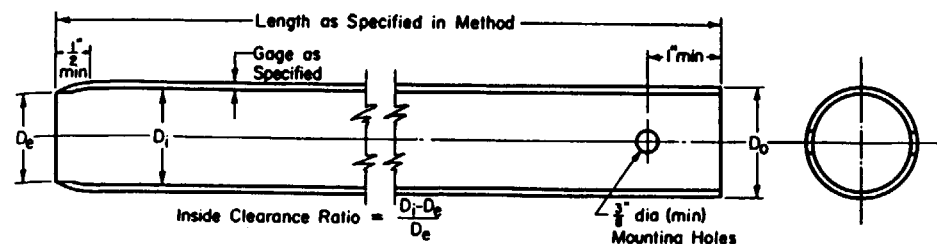
Outside diameter:	2	3	5
in.	50.8	76.2	127
mm			
Wall thickness:			
Bwg	18	16	11
in.	0.049	0.065	0.120
mm	1.24	1.65	3.05
Tube length:			
in.	36	36	54
m	0.91	0.91	1.45
Clearance ratio, %	1	1	1

⁴ The three diameters recommended in Table 1 are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Lengths of tubes shown are illustrative. Proper lengths to be determined as suited to field conditions.

TABLE 2 Dimensional Tolerances for Thin-Walled Tubes
Nominal Tube Diameters from Table 1⁴ Tolerances, in.

Size Outside Diameter	2	3	5
Outside diameter	+0.007 -0.000	+0.010 -0.000	+0.015 -0.000
Inside diameter	+0.000 -0.007	+0.000 -0.010	+0.000 -0.015
Wall thickness	±0.007	±0.010	±0.015
Ovality	0.015	0.020	0.030
Straightness	0.030/ft	0.030/ft	0.030/ft

⁴ Intermediate or larger diameters should be proportional. Tolerances shown are essentially standard commercial manufacturing tolerances for seamless steel mechanical tubing. Specify only two of the first three tolerances; that is, O.D. and I.D., or O.D. and Wall, or I.D. and Wall.



- NOTE 1—Minimum of two mounting holes on opposite sides for 2 to 3½ in. sampler.
 NOTE 2—Minimum of four mounting holes spaced at 90° for samplers 4 in. and larger.
 NOTE 3—Tube held with hardened screws.
 NOTE 4—Two-inch outside-diameter tubes are specified with an 18-gage wall thickness to comply with area ratio criteria accepted for "undisturbed samples." Users are advised that such tubing is difficult to locate and can be extremely expensive in small quantities. Sixteen-gage tubes are generally readily available.

Metric Equivalents

in.	mm
½	6.77
¾	12.7
1	25.4
2	50.8
3½	88.9
4	101.6

FIG. 1 Thin-Walled Tube for Sampling

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Standard Test Method for DENSITY OF SOIL IN PLACE BY THE DRIVE-CYLINDER METHOD¹

This standard is issued under the fixed designation D 2937; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers the determination of in-place density of soil by the drive-cylinder method. The test method involves obtaining a relatively undisturbed soil sample by driving a thin-walled cylinder and the subsequent activities for the determination of in-place density. Two procedures are described for this test, one for testing at the surface, and one for testing at greater depths.

1.2 This test method is not appropriate for sampling organic soils, very hard soils which cannot be easily penetrated, soils of low plasticity which will not be readily retained in the cylinder, or soils which contain appreciable amounts of coarse or granular material.

1.3 This test method is limited to the procedures necessary for obtaining specimens suitable for determining the in-place density and water content of certain soils. The procedures and precautions necessary for obtaining undisturbed samples suitable for laboratory testing or otherwise determining engineering properties is beyond the scope of this test method.

NOTE 1—The general principles of this test method have been successfully used to obtain samples of some field compacted fine-grained soils having a maximum particle size of 4.75-mm for purposes other than density determinations such as the testing for engineering properties.

1.4 Values may be stated in inch-pound, gram-centimetre, or other units, provided the appropriate conversion factors are used to maintain consistency of units throughout the determinations and calculations.

1.5 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety prob-

lems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Applicable Documents

2.1 ASTM Standards:

D653 Terms and Symbols Relating to Soil and Rock²

D698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop²

D1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop²

D2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock and Soil-Aggregate Mixtures²

3. Significance and Use

3.1 This test method can be used to determine the in-place density of natural, inorganic, fine-grained soils.

3.2 This test method may also be used to determine the in-place density of compacted soils used in construction of structural fill, highway embankments, or earth dams.

3.3 This test method is not recommended for

use in organic, noncohesive, or friable soils. This test method is not applicable to soft, highly plastic, or saturated or other soils which are easily deformed, or which may not be retained in the drive cylinder. The use in fine-grained soils containing appreciable coarse material may not yield meaningful results and may damage the drive-cylinder equipment.

4. Apparatus

4.1 *Drive Cylinders*, with diameters of approximately 2 to 5½ in. (50 to 140 mm) or larger. Typical details of two types of drive cylinders with outside diameters of 3.0 in. (76.2 mm) are shown in Figs. 1 and 2. Drive cylinders of other diameters will require proportional changes in the drive-cylinder tube and drive-head dimensions. The volume of the cylinders with the dimensions shown in Figs. 1 and 2 is approximately 0.01 ft³ (283 cm³). The apparatus shown in Fig. 1 is of a design suitable for use at or near the surface. The threaded apparatus shown in Fig. 2 is of a design for use at greater depths.

4.1.1 The number of cylinders required depends on the number of samples to be taken and the anticipated rapidity by which the cylinders can be returned to service after weighing, cleaning, etc. A minimum of six cylinders is recommended.

4.1.2 The cylinders shown in Figs. 1 and 2 meet the wall thickness and area-ratio requirements as set forth by Hvorslev³ for drive samplers, this is 10 to 15%, as defined by the following:

$$A_r = [(D_e^2 - D_i^2)/D_i^2] \times 100$$

where:

A_r = area ratio, %,

D_e = maximum external diameter of the drive sampler, and

D_i = minimum internal diameter of the drive sampler at the cutting edge.

Cylinders of other diameters should conform to these requirements.

4.1.3 When the in-place density is to be used as a basis for acceptance of compacted fill, the cylinders shall be as large as practical to minimize the affects of errors and shall in no case be smaller than 0.025 ft³ (710 cm³). This will require cylinders larger than those shown in Figs. 1 and 2.

4.2 *Drive Head*—The typical details of the drive heads and appurtenances are shown in Figs.

1 and 2. The drive head for use at or near the surface has a sliding weight for driving the cylinder. The cylinder to be used at greater depths is driven with a hammer or other means. For sampling below shallow depths, extensions may be added to the drive rod as required to reach the layer to be sampled.

4.3 *Straightedge*, steel, approximately ¼ by 1½ by 12 in. with one edge sharpened at approximately a 45° angle for trimming the ends of the sample flush with the cylinder.

4.4 *Auger*—An Iwan or similar type auger for digging below shallow depths.

4.5 *Shovel*—Any one of several types of shovels or spades is satisfactory in shallow sampling for digging the cylinders out after they have been driven into the soil.

4.6 *Balances*—A balance or scale of at least 1-kg capacity accurate to 1.0-g and a balance of 500-g capacity accurate to 0.1-g are required for the cylinders shown in Figs. 1 and 2. Larger cylinders will require a balance of 20-kg capacity accurate to 0.1 %.

4.7 *Drying Equipment*—Equipment and oven to comply with Method D 2216. Other drying equipment may be used for rapid evaluation of moisture content if specified (see 7.2).

4.8 *Miscellaneous Equipment*—Brushes, sledgehammers, plastic bags, metal cans with lids, or other suitable containers for retaining the drive cylinder and sample until determination of mass and drying, spoons, inside/outside vernier caliper, or the equivalent accurate to 0.01 in. (0.0025 mm) for calibration, gloves, and safety glasses.

5. Calibration

5.1 Before testing begins and periodically thereafter, or when damage is suspected, check the cutting edge of the drive cylinders (dulled or damaged cylinders may be resharpened and reweighed or discarded).

5.1.1 Before testing and periodically thereafter, determine the mass and volume of each cylinder. Determine and record the mass accurately to the nearest 1 g. Determine the volume of each cylinder by measuring the height and the swaged-end diameter at four equally spaced points to 0.01 in. (0.254 mm) and average the

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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² Annual Book of ASTM Standards, Vol 04.08.

³ Hvorslev, M. J., "Surface Exploration and Sampling of Soils for Engineering Purposes," Engineering Foundation, 345 E. 47th St., New York, NY, 10017.

respective dimensions. Calculate and record the volume to the nearest 0.01 in.³ (0.16 mm³).

5.2 Permanently identify each cylinder by a number or symbol traceable to the calibration data. It may be desirable in some cases to show the mass and volume on the cylinder along with the identification.

6. Sampling

6.1 Sampling at or Near the Surface:

6.1.1 Brush all loose particles from the surface. For near-surface sampling (not more than 36 in. (1 m) in depth), sample through a hole bored with an auger or dug by a shovel from which loosened material has been removed. Obtain a fairly level surface before any cylinder is driven. Depending on the soil texture and moisture, the surface may be prepared utilizing a bulldozer blade or other heavy equipment blades provided the sample area and vicinity are not deformed, compressed, torn, or otherwise disturbed.

6.1.2 Assemble the cylinder and drive head with the sharpened edge on the surface to be sampled. Drive the cylinder by raising the drop hammer and allowing it to fall. Hold the drive rod in a steady and vertical position, keeping the drive head in contact with the cylinder. Continue driving until the top of the cylinder is approximately 1/2 in. (13 mm) below the original surface. Overdriving may result in deforming or compressing the sample and may provide erroneous results. Care should be taken to prevent overdriving, particularly when sampling below the surface. If overdriving occurs or is suspected, the sample should be discarded and the soil resampled. Remove the drive head and dig the cylinder from the ground with a shovel, digging the soil from around the sides of the cylinder and undercutting several inches below the bottom of the cylinder before lifting the cylinder out. When sampling near, but below, the surface, use the same procedure, but more soil will necessarily have to be dug from around the sides of the cylinder to properly undercut the cylinder.

6.1.3 After the cylinder has been removed from the ground, trim any excess soil from the sides of the cylinder. Using the straightedge, trim the ends of the sample flush and plane with the ends of the cylinder. A satisfactory sample is composed of relatively undisturbed soil representative of the soil in place and shall not contain

rocks, roots, or other foreign material. If the cylinder is not full or is not representative, discard the sample and take another sample. If the cylinder is deformed or otherwise damaged while driving it into or removing it from the ground, discard the sample and repair or replace the cylinder. Immediately determine the mass of the sample and determine the water content or place the drive cylinder and sample in a container which will prevent soil or water loss until mass and water determinations can be made.

6.2 Sampling Below the Surface:

6.2.1 Drill a hole with an auger to the elevation of the layer to be sampled. Clean the bottom of the hole of auger-loosened material as well as possible with a cleaning auger or other suitable tool leaving the bottom of the hole fairly level.

6.2.2 Assemble the cylinder to the drive head (and extensions if needed) and lower the cylinder into the hole placing it firmly on the layer to be sampled. Drive the cylinder into the soil by blows of a hammer on the top of the drive rod. Continue driving until the top of the cylinder is approximately 1 in. (25 mm) below the surface being sampled. Care must be taken not to overdrive since there is only approximately a 2-in. (50-mm) clearance in the drive head. Break the sample from the ground by moving the rod of the sampler back and forth. Remove the assembly from the hole and carefully remove the cylinder from the drive head. In cases where the sample breaks from the ground slightly above the cutting edge, the sample may be forced back through the cylinder by carefully pressing the top of the sample against a flat surface. Trim any excess soil from the cylinder using the straightedge until the sample is flush and plane with the ends of the cylinder. If the cylinder is deformed or damaged, or if the sample is broken, disturbed, or gouged by rocks during driving, discard the sample. Immediately determine the mass of a satisfactory sample and determine the water content or place the drive cylinder and sampler in a container which will prevent soil or moisture loss until mass and water content determinations can be made.

7. Procedure

7.1 Determine the mass of the drive cylinder and soil sample to the nearest 1 g and record.

7.2 Remove the soil from the cylinder. Obtain a representative specimen for water content de-

termination, or use the entire sample. Specimens for determining water content are to be as large as practical but in no case smaller than 100 g and selected in such a way so as to represent all the material from the cylinder. Determine the water content of the soil in accordance with Method D2216. Rapid methods of water content determination may be used when specified. Rapid methods are generally less accurate than Method D2216 and should only be used when their accuracy is considered sufficient for the testing purpose.

8. Calculations

8.1 The in-place dry density of the soil is expressed as the mass of the dry soil divided by the volume of soil, and is usually reported in pounds per cubic foot or kilograms per cubic metre.

8.2 Calculate the dry mass of the drive-cylinder sample, M_2 , in grams, as follows:

$$M_2 = [(M_1 - M_3)/(100 + w)] \times 100$$

where:

M_1 = mass of the cylinder and wet soil sample, g.

M_2 = mass of the cylinder, g, and

w = water content, %, dry mass basis.

8.3 Calculate the dry density, ρ_d , of the drive-cylinder sample in lb/ft³ as follows:

$$\rho_d = (M_2/V) (3.810)$$

where:

V = volume of the drive cylinder, in³ (to the nearest 0.01 in³)

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NOTE 2—It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory maximum density, determined in accordance with Test Methods D 698. This relation can be determined by dividing the in-place density by the maximum density and multiplying by 100.

9. Report

9.1 The report shall include the following:

9.1.1 Location,

9.1.2 Depth below ground surface or elevation of surface, or both,

9.1.3 Dry density,

9.1.4 Water content,

9.1.5 Dimensions and volume of the sampler,

9.1.6 Visual description of the soil sample, and

9.1.7 Comments on soil sample disturbance.

10. Precision and Bias

10.1 The precision and bias of this test method for measuring the density of soils in place by the drive-cylinder method has not been determined. No available methods provide absolute values for the density of the soil in-place against which this method can be compared. The variability of the soil and the destructive nature of the test method do not allow for the repetitive duplication of test results required to obtain a meaningful statistical evaluation. Precision is a function of the care exercised in performing the steps of the test method given, with attention to systematic repetition of the procedure and equipment maintenance.

